PHYTOREMEDIATION FIELD STUDIES DATABASE for CHLORINATED SOLVENTS, PESTICIDES, EXPLOSIVES, and METALS

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NOTICE

This document was prepared by two undergraduate students under internships with United States Environmental Protection Agency (EPA). Ana Hoffnagle was sponsored by the University of Arizona and Cynthia Green was sponsored by the Environmental Careers Organization.

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The paper briefly explains the concept of phytoremediation, details phytoremediation site considerations, and summarizes the successes and failures of field-scale sites where phytotechnologies have been applied or proposed. Project tasks were accomplished by two summer interns via literature searches, site visits and personal communications with site managers and other officials. No attempts were made to independently confirm the resources used. It has been reproduced to help provide federal agencies, states, consulting engineering firms, private industries, and technology developers with information for use in determining whether phytoremediation technology is a feasible option for a site. The report is available on the Internet at www.clu-in.org/studentpapers/.

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1. OBJECTIVES

1.1 Scope of Project

The scope of this project is to compile a listing of sites where field-scale phytotechnologies have been applied to contain and remediate chlorinated solvents, pesticides, explosives and heavy metals in contaminated soil and groundwater. Phytomechanisms included in this project shall include phytoaccumulation, phytoextraction, rhizofiltration, phytostabilization, rhizodegradation, phytodegradation, phytovolatilization and hydraulic control. Older phytoremediation databases will be updated and appended by information extracted from government internet sources, literature searches and personal communication with site contacts.

1.2 Requirements

The following criteria have been set for the database:

1. Project scale shall be demonstration, pilot or full-scale. Laboratory, bench or greenhouse scale phytoremediation research shall not be included.
2. Phytoremediation installations of constructed wetlands sites, landfill vegetative cover sites, and riparian buffers shall be excluded from the database.
3. Media type shall be limited to soil and groundwater. Wastewater, surface water, sediment, and sludge applications shall not be included.
4. Vegetative types include all members of the plant kingdom and fungi.

1.3 Concept of Operation

The purpose of this compilation is to provide an understanding of the successes and failures of phytoremediation installations to-date. This paper will serve as a reference for federal, state, and site managers and others to compare their site with others having similar conditions in order to support the decision of whether or not to use phytoremediation as a treatment technology. A spreadsheet has been selected as the layout for the database in order to accommodate public navigation. Entries in the database shall attempt to summarize the relevant logistics, successes and failures of each site by defining twenty-one fields for each. These elements include:

1. Site Name
2. Site Location
3. Contaminant
4. Vegetation Type
5. Planting Descriptions
6. Media Type
7. Site Characterizations
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19. Comments
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21. Citation

Each site profile will allow users to quickly determine the nature of the site and the success of the technology while also providing avenues to pursue should they want further site information.

2. OVERVIEW

2.1 Phytoremediation

2.1.1 What Is Phytoremediation?

Phytoremediation is the use of vegetation and its associated microorganisms, enzymes and water consumption to contain, extract or degrade contaminants from soil and groundwater. Both organic and inorganic contaminants can be successfully contained or degraded using phytoremediation in a variety of media (i.e. soil, sediment, sludge, wastewater, groundwater, leachate and air) (Susarla, 2002). The mechanisms of phytoremediation include:

- Phytoextraction – removal and storage of contaminants from the media into the plant tissue;
- Rhizodegradation – degradation of contaminants by microorganisms in the soil zone that surrounds and is influenced by the roots of plants, also known as the rhizosphere;
- Phytodegradation – degradation of contaminants within the plant tissue;
- Phytostabilization – isolation and containment of contaminants within soil through the prevention of erosion and leaching;
- Phytovolatilization – uptake and transpiration of contaminants from the media through the plant tissue into the atmosphere; and
- Hydraulic Control – containment of contaminants within a site by limiting the spread of a contaminant plume through plant evapotranspiration.

In depth details on phytoremediation mechanisms have been thoroughly documented in past literature and are not the focus of this document (McCutcheon, 2003).

2.1.2 History

The concept of using plants to clean and restore soil and wastewater has been employed for over 300 years. Numerous bench-scale studies have been performed to determine plant toxicities and contaminant uptake abilities. In order for phytoremediation to achieve acceptance as a remedial method, field-scale applications need to be performed and documented. Constructed wetlands and vegetative covers have been extensively applied in the field to demonstrate their ability to remediate contamination and their data has been well documented (McCutcheon, 2003). More recently, field-scale studies of groundwater and soil plantations have been performed to determine their effectiveness in remediating contamination. The purpose of this paper is to document groundwater and soil plantation applications and their results, so that the information will be useful in assessing the feasibility of phytoremediation as a remedial technology for a site.

2.1.3 Advantages and Disadvantages

Phytoremediation, like other technologies, has both advantages and disadvantages associated with it as shown in Table 1. Advantages and disadvantages are not ranked in any order. The weight each element carries will vary with each site.

Table 1. Phytoremediation Advantages and Disadvantages (ITRC, 2004; EPA, 2001)

Advantages	Disadvantages
▪ Cost reduced over traditional methods	▪ Long remediation time requirement
▪ Low secondary waste volume	▪ Effective depth limited by plant roots
▪ Improved aesthetics	▪ Phytotoxicity limitations
▪ Habitat creation - biodiversity	▪ Fate of contaminants often unclear
▪ Green technology	▪ Climate dependent/variable
▪ More publicly accepted	▪ Seasonal effectiveness
▪ Provide erosion control	▪ Potential transfer of contaminants (i.e. to animals or air)
▪ Prevent runoff	▪ Harvesting and disposal of metals in biomass as hazardous waste may be required, although generally not
▪ Reduce dust emission	▪ Larger treatment footprint
▪ Reduce risk of exposure to soil	
▪ Less destructive impact (applied in-situ)	

Not all listed advantages and disadvantages are specific to phytoremediation. Footprint size limitations may affect all remediation technologies. Advances in technology have been able to alleviate some of the disadvantages. Deeper root depths are achievable today than in the past due to engineered planting methods (see section 2.2.5). Phytotoxicity has become less of an issue as genetically modified plants (see section 2.2.7) have been developed to withstand higher concentrations of contaminants. More disadvantages may be overcome as the technology progresses.

2.1.4 Use in a Treatment Train

Though not always used as a stand alone technology, phytoremediation can still be a benefit to many hazardous waste sites. Few hazardous waste sites apply phytoremediation as the sole treatment method. The technology is often applied in conjunction with other traditional methods or as the final phase of a treatment train after contaminant concentrations have been reduced.

Phytoremediation can be used as part of a treatment train when time constraints require other methods to be employed to achieve a remediation goal in a short period of time. This usually occurs when high contaminant concentrations in sensitive areas (i.e. near drinking water sources) require quick reduction. A series of remediation efforts may be undertaken to reduce the concentrations to an acceptable level before applying phytoremediation as the last "polishing step" to remediate and contain low level concentrations.

Phytoremediation can also be applied in conjunction with other technologies to achieve a treatment goal. The natural solar-powered pumping of deep rooted trees may need to be coupled with traditional pump-and-treat systems to maintain treatment rates during the less effective growing months of the winter season. Vegetation may also be planted around site perimeters and "hot spots" to maintain hydraulic control and prevent contamination migration, while traditional methods are applied to remediate the source. Research on the addition of inorganic, organic and bio-amendments in conjunction with phytoremediation has also shown promising results (Kelley, et.al, 2000).

2.1.5 Cost

The first costs incurred when approaching any hazardous waste site are those of site assessment. Regardless of the technology applied, the nature and extent of contamination, hydrological and geological characteristics and site characteristics must all be assessed. Costs incurred during this phase are similar for all technologies. Beyond site assessment, phytoremediation will have unique costs associated with it. These cost considerations can be divided into four primary categories: (1) Design, (2) Installation (3) Operation and Maintenance, and (4) Sampling and Analysis.

Design considerations include feasibility studies, plant selection and the associated engineering costs. Land obstructions at the site may have to be incorporated into the design or removed. Green house studies or pilot scale testing may be needed to determine which plants to use and assess the possibility of phytoremediation as a treatment option for the site. Like all designs, the salaries of engineers performing conceptual work for the site will be the dominant cost in the design phase.

Installation costs include site preparation, soil preparation, materials and labor. In order to prepare the site, it may need to be cleared, leveled or fenced in. Soil preparation may involve pH adjustment, nutrient addition or tilling. Site and soil preparations will require labor and materials including heavy equipment, organic matter, irrigation systems, plant stock (including 10-20% excess for replanting needs (ITRC, 2004)) and vector protection materials for the plants.

Operation and Maintenance (O&M) costs will include monitoring equipment, power sources, maintenance for the equipment and labor are included. Specific O&M requirements for phytoremediation are detailed in section 2.5 of this document.

Sampling and Analysis costs may dominate the overall cost of the project due to the length of time monitoring is required and the extent of data necessary. Costs include labor or machinery to collect samples and lab work fees associated with analyzing samples. Data collected during sampling and analysis is crucial for thorough documentation of site progress and the performance of phytoremediation as a new technology. The EPA is collaborating with state and federal partners on implementing a streamlined approach to sampling, analysis and data management methods. This approach, called the Triad Approach, has the potential to reduce costs associated with sampling and analysis (EPA, 2004).

The costs associated with these four categories are relatively small compared to those of traditional remediation technologies. This is especially true in the operation and maintenance phase where the primary factor in cost reduction is the energy source of the operating systems. Traditional systems utilize electric power, at a substantial cost, to pump water, whereas phytoremediation systems take advantage of free solar energy. Individual sites will vary in cost regardless of the technology being applied. In general, phytoremediation is a low cost alternative to traditional methods as can be seen in the cost estimates of Table 2.

Table 2. Cost Comparisons: Phytoremediation vs. Traditional Technologies

Traditional Method	Scenario	Estimated Cost		Reference
		Traditional Method	Phytoremediation	
Pump and Treat	1-acre site with 20-foot-deep Aquifer	$660,000	$250,000	Gatliff, E. (1994)
Conventional Technology	Army Ammunition Plant	$1 trillion	$1.8 million	Matso, K. (1995)
Traditional Curb and Gutter	SEA Streets Runoff Buffer	$1 million	$850,000	ITRC (2004)
Standard Landfill Cap	Landfill Vegetative Cap - College Park	$10 million	$3-4 million	ITRC (2004)
Activated Carbon System	Army Ammunition Plant - Milan	$4.00/ 1000 gal	$1.80/ 1000 gal	ITRC (2004)
Pump & Treat / Iron Barrier	PCE in Groundwater	8.90/5.30 $/1000 gal	$2.00/1000 gal	Schnoor (2002)
Flushing/ Vitrification	Metals in Soils	75-210/300-500 $/Ton	$25-100/Ton	Schnoor (2002)

2.2 Contaminant Information

The database contained in this document focuses on four of the major contaminant groups found at hazardous waste sites.

2.2.1 Chlorinated Solvents

The term *chlorinated solvents* refers to a family of colorless, liquid-phase hydrophobic organics containing one or more chlorine atoms. Most chlorinated solvents are only slightly soluble in water and, with the exception of vinyl chloride, have densities greater than that of water as shown in Table 3. This combination leads to their formation of dense non-aqueous phase liquid (DNAPL). Chlorinated solvent plumes tend to take a long time to remediate when DNAPL is present, because it acts as a slow releasing, continuous source. Common uses of chlorinated solvents include drycleaning operations, degreasing operations, polymer manufacturing and as a chemical intermediate. Because of their wide use, chlorinated solvents dominate the listings of hazardous waste at sites nation wide, with trichloroethylene (TCE) present at 40% off all Superfund sites in the United States (McCutcheon, 2003; USGS, 2004a). Contamination of soil and groundwater with chlorinated solvents is largely due to accidental spills and poor handling and disposal practices prior to regulation of the chemicals.

The primary chlorinated solvents at hazardous waste sites are trichloroethylene (TCE), perchloroethylene (PCE) and polychlorinated biphenyls (PCBs), with TCE and PCE being the most dominant (USGS, 2004a). TCE is primarily used as a metal cleaning agent and in specialty adhesives. It is a probable carcinogen and can affect kidneys, liver, lungs, and heart rate. PCE is primarily used as a drycleaning and metal cleaning agent. PCE is not classified as a carcinogen but has been known to affect the central nervous system and cause irritation of the skin, eyes, and upper respiratory system (Evans, 2000). PCBs are synthetic oils that do not readily react at room temperature. They are primarily used as coolants and/or insulators and were previously used as a spray to control dust on dirt roads (ASTDR, 2004). PCBs are classified as probable carcinogens by the EPA and the International Agency for Research on Cancer. PCB contamination is an ecological concern, because by-products from burning them at low temperatures are carcinogenic and their presence in the food chain has affected eggshell formation in birds (ASTDR, 2004).

Traditional methods for remediating chlorinated solvent contamination include natural attenuation, soil vapor extraction, air sparging and pump and treat. Phytoremediation mechanisms that have been successful in containing and/or remediating chlorinated solvents include rhizodegradation, phytodegradation, phytovolatilization and hydraulic control using hybrid poplar and willow trees as can be seen in the Database of Chlorinated Solvent Phytoremediation in Appendix A of this document.

Table 3. Common Chlorinated Solvents

Compound Name	Chemical Formula	MW (g/mol)	Density (g/mL-20°C)	Solubility (g/100mL-20°C)	Log K_{ow}
Carbon Tetrachloride	CCl_4	153.823	1.594	0.08048	2.64
Chloroform	$CHCl_3$	119.3779	1.498	0.795	1.97
3,3-Dichlorobenzidine	$C_{12}H_{10}Cl_2N_2$	253.1304		0.00123	3.21, 3.5
1,1-Dichloroethene	$C_2H_2Cl_2$	96.9438	1.213	0.225	1.32
cis-1,2-Dichloroethene	$C_2H_2Cl_2$	96.9438	1.284	0.08	1.86
trans-1,2-Dichloroethene	$C_2H_2Cl_2$	96.9438	1.257	0.63	2.09 [a]
1,1-Dichloroethane	$C_2H_4Cl_2$	98.9596	1.176	0.506	1.79
1,2-Dichloroethane	$C_2H_4Cl_2$	98.9596	1.253	0.8608	1.48
Methylene Chloride	CH_2Cl_2	84.9328	1.325	1.32	1.3
Perchloroethylene	C_2Cl_4	165.834	1.623	0.015	3.4
Polychlorinated Biphenyls	*	*	*	*	*
1,1,1-Trichloroethane	$C_2H_3Cl_3$	133.404	1.3376	0.1495	2.49

Compound Name	Chemical Formula	MW (g/mol)	Density (g/mL-20°C)	Solubility (g/100mL-20°C)	Log K_{ow}
1,1,2-Trichloroethane	$C_2H_3Cl_3$	133.404	0.442	1.4411	2.42
Trichloroethylene	C_2HCl_3	131.388	1.462	0.11	2.42
Vinyl Chloride	C_2H_3Cl	62.4987	0.9106	0.11	1.36

Data for this table extracted from the NIST Chemistry Webbook, Cambridge Chemfinder, the Agency for Toxic Substances and Disease Registry (ATSDR) ToxFaqs™ and Pankow and Cherry (1996)
* 209 possible PCBs. See the ATSDR internet resources at http://www.atsdr.cdc.gov/toxfaq.html for data.
[a] recommended.

Tree core sampling is an emerging technology that shows promising use as a tool to detect the presence of chlorinated solvents at sites. Researchers have been investigating the concentration of chemicals in tree trunks since 1990 (Vroblesky, 1990). Recently, the analysis of tree cores has gained interest in the field of phytoremediation as a low-cost and easily employable method to assess contamination presence. Core samples are collected from trees using a small borer and quickly placed in septum-capped vials to minimize loss of contaminant to volatilization. Vials are stored overnight at room temperature to allow diffusion of the volatile organic compounds from the core into the vial headspace. Headspace samples are analyzed and compared to standards using gas chromatography. Concentrations of the contaminants in the core are determined by assuming partitioning of contaminants from the cores is similar to that between air and water and taking into account recent findings on partitioning between air/wood and wood/water. Studies at the Riverfront Superfund Site show a strong relationship between contaminant concentrations in trees and shallow soils but a weak one between trees and groundwater (USGS, 2004b).

2.2.2 Pesticides

Pesticides are defined by the EPA as any substance or mixture of substances used for preventing, destroying, repelling, or mitigating any pest. The term is used broadly to include herbicides, fungicides, and other pest-control substances. In 1998 and 1999, world pesticide usage exceeded 5.6 billion pounds. US pesticide usage exceeded 1.2 billion pounds (EPA, 2002), and pesticides were applied at over 900,000 farms and 70 million households (Delaplane, 2000). Heavy usage over the years (mostly via direct land application) of some of the more persistent pesticides has resulted in their ubiquitous dispersal, most typically in aquatic environments (Chaudhry, 2002). For example, traces of a number of organochlorine pesticides have been found in Arctic environments where no previous application has occurred (Oehme, 1991).

EPA regulates pesticides because of risks that vary considerably depending on the toxicity of chemical components and dosage. For example, the most widely used class of pesticides, organophosphates, is implicated in a number of nervous system ailments and is first among pesticides most often implicated in symptomatic illnesses. Organophosphates, however, are typically not persistent in the environment (EPA, 1999). On the other hand, organochloride insecticides can be extremely recalcitrant. Several have had production curtailed or been banned due to deleterious environmental and health effects. Some especially recalcitrant pesticide pollutants, including aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, toxaphene, mirex, and hexachlorbenzene, were placed on the 2001 Convention on Persistent Organic Pollutants "dirty dozen" list to immediately address regulatory concerns. Some properties of more commonly remediated pesticides, including persistence, K_{ow}, and health effects, are shown in table 4 on the next two pages.

Pesticide persistence in the environment depends on various chemical factors specific to the contaminant, such as volatility, solubility, chemical reactivity, soil-water (K_d) and octanol-water (K_{ow}) partitioning, and absorption and adsorption characteristics. In addition, biological degradability factors from microbial and plant activity also have significant effects (Chaudhry, 2002). The polar/nonpolar partitioning is particularly crucial in determining contaminant uptake and translocation in plants, with optimum log K_{ow} conditions around 1.8 (Briggs,1982) and with uptake occurring roughly in the range of 1-3.5 (Hsu, 1992). Other issues to consider when evaluating the persistence of pesticides include the formation of tightly bound pesticide residues (Barraclough, 2004), degradation to still-active pesticide products, and decreased bioavailability as they age (Alexander, 2000). For example, a study by Knuteson *et al.* (2002) examined the effect of age on simazine uptake, finding that concurrent with an increase with age was increasing pesticide tolerance, but lower rates of uptake. Other studies have evaluated successful uptake of weathered chlordane in food crops (Mattina, 2000) and in pasture species (Singh, 1992), but less successful was the phytoremediation of dieldrin (Singh, 1992). More recently, White *et al.* (2003) studied the effect of weathered (aged) p-p'-DDE on uptake and translocation into 21 different cultivars (two subspecies) of summer squash. They found over an order-of-magnitude difference in p,p'-DDE tissue concentrations among the various cultivars' abilities to uptake the weathered contaminant, and attributed differences to subspecies variation of root exudate character.

Traditional methods of pesticide remediation include excavation and/or chemical oxidation processes (i.e. photocatalysis, ozonation, iron-catalyzed Fenton's reaction) or thermal processes (i.e. low temperature themal desorption, incineration). Bioremediation and phytoremediation are the biotic processes that are sometimes employed. The use of phytotechnologies to remediate these more persistent pesticides is only emerging. Difficulties remain, including the potential phytotoxicity of some compounds (i.e. herbicides) that were originally developed destroy plant material. Typically the mechanisms involved in pesticide phytoremediation are phytodegradation, rhizodegradation, and phytovolatilization. Recently, Karthikeyan *et al* (2004) reviewed various plant and rhizosphere systems that have shown potential in the laboratory for future pesticide phytoremediation.

Table 4: Common Pesticides

Pesticide	Molecular formula	Molecular weight	Density (g/mL)	Aqueous Solubility (mg/L)	Log Kow	Persistence (Half-life)	Health Effects
Alachlor	$C_{14}H_{20}ClNO_2$	269.8	1.133	242	2.92	8 days	Effects on liver, spleen, kidney, iris, lung effects for long (6+ month) exposures
Aldrin	$C_{12}H_8Cl_6$	364.93	1.6	0.017	6.5	20 days to 1 year	Nervous system effects. Probable carcinogen. Large doses: convulsions, death. Moderate doses: dizziness, headaches, vomiting, uncontrolled muscle movement.
Atrazine	$C_6H_{14}ClN_5$	215.7	1.187	70	2.68	60 to 100 days	Acute: abdominal pain, diahrrea, skin and mucous membrane irritation (low levels); incoordination, muscle spasms, hypothermia, hypoactivity, prostration, convulsions, death (higher does). Chronic: respiratory distress, limb paralysis, structural/ chemical
Chlordane	$C_{10}H_6Cl_8$	409.78	1.6	0.056	6	4 years	Nervous system, digestive system, liver effects. Headaches, irritability, confusion, weakness, vision problems, vomiting, stomach cramps, diarrhea, and jaundice for lower doses. Higher doses: convulsions and death.
Dichlorodiphenyltri-chloroethane (DDT)	$C_{14}H_9Cl_5$	354.49	1.55	0.0055	6.19	2 to15 years	Nervous system effects (tremors, seizures); probable carcinogen
Dieldrin	$C_{12}H_8Cl_6O$	380.92	1.75	0.2	5.48	Up to 7 years	Nervous system effects. Probable carcinogen. Large doses: convulsions, death. Moderate doses: dizziness, headaches, vomiting, uncontrolled muscle movement.
Endrine	$C_{12}H_8Cl_6O$	380.92	1.7	0.26	5.2	Up to 12 years	Nervous system effects (large doses can cause severe central nervous system injury, convulsions, death; smaller doses can cause headaches, confusion, nausea, vomiting, and convulsions); birth defects
Heptachlor	$C_{10}H_5Cl_7$	373.32	1.58	0.18	5.47-6.10	0.4 to 2 years	Nervous system damage, liver and adrenal gland damage, tremors
Hexachlorobenzene (HCB)	C_6Cl_6	284.81	2.044	0.005	5.73	2.7 to 7.5 years	Damage to liver, thyroid, nervous system, bones, kidneys, blood, and immune systems; reasonably anticipated to be carcinogen

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Pesticide	Molecular formula	Molecular weight	Density (g/mL)	Aqueous Solubility (mg/L)	Log Kow	Persistence (Half-life)	Health Effects
Metribuzin	$C_8H_{14}N_4OS$	214.28	1.28	1050	1.7	40 days	Skin irritation, reduced weight gain, blood chemistry changes, liver and kidney damage, enlarged liver and thyroid glands with chronic exposure.
Mirex	$C_{10}Cl_{12}$	545.55	1.8	0.085	7.18	Up to 10 years	Stomach, intestine, liver, kidney, eye, thyroid, nervous system, and reproductive system effects; possible carcinogen
Pentachlorophenol (PCP)	C_6Cl_5OH	266.34	1.98	80	5.01	45 days	Respiratory irritation, lund oedema, dermatitis, and effects on cardiovascular system, central nervous system, kidneys, lungs, liver.
Toxaphene	$C_{10}H_{10}Cl_8$	414	1.66	0.55	5.78-6.79	1 to14 years	Damage to lungs, nervous system, kidneys, death at high doses; lower doses effect liver, kidneys, adrenal glands, and immune system; possible carcinogen
Data for this table extracted from the Cambridge Chemfinder, the Extension Toxicology Network, & the Agency for Toxic Substances and Disease Registry							

2.2.3 Explosives

The term *explosive* refers to prepared chemicals subject to a rapid chemical reaction that produce or cause explosions. The three main classes of explosives are nitroaromatics, nitramines and nitrate esters. Nitroaromatics are characterized by an aromatic ring and nitro groups. The electronegativity of the nitro groups prevents explosives from readily falling under electrophilic attack. For this reason they are generally non-hygroscopic, insoluble in water and do not readily react with metals. Common uses of explosives include military weapons and pyrotechnic shows. Table 5 lists common explosives and some of their properties.

Contamination of soil with explosives is largely due to manufacturing, storage, testing and inappropriate waste disposal of explosive chemicals. The primary explosives at hazardous waste sites are 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (**R**oyal **D**emolition e**X**plosive-RDX) and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazine (**H**igh **M**elting e**X**plosive-HMX). TNT is a nitroaromatic constituent of many explosives. In a refined form, TNT is stable and can be stored over long periods of time. It is relatively insensitive to blows or friction. It is readily acted upon by alkalis to form unstable compounds that are very sensitive to heat and impact. Health effects due to exposure to TNT include anemia, abnormal liver function, skin irritation, and cataracts (ASTDR, 2004). RDX is a nitramine widely used as an explosive and as a constituent in plastic explosives. RDX can cause seizures when large amounts are inhaled or eaten. Long-term health effects on the nervous system due to low-level exposure to RDX are not known. HMX is a nitramine that explodes violently at high temperatures. It is used in nuclear devices, plastic explosives and rocket fuels. Insufficient studies on the effects of HMX to the health of humans and animals have been performed.

Incineration, landfilling and pump and treat systems are traditional methods applied to remove explosives contamination from soil and groundwater. These approaches are expensive and can cause air pollution with ash generation. Phytoremediation mechanisms that have been successful in containing and/or remediating explosives contamination include phytoextraction, phytodegradation and phytostabilization using tobacco, periwinkle, and parrot feather plants in constructed wetlands (Bhadra, 1999; Wayment, 1999; Hughes, 1997).

Table 5. Common Explosives

Compound Name	Chemical Formula	MW (g/mol)	Density (g/mL-20°C)	Solubility (g/100mL-20°C)
2,4-Dinitrotoluene (2,4DNT)	$C_7H_6N_2O_4$	182.1354	1.521	0.027
2,6-Dinitrotoluene (2,6DNT)	$C_7H_6N_2O_4$	182.1354	1.2833	0.0182
2-nitrotoluene	$C_7H_7NO_2$	137.1378	1.163	0.06
4-nitrotoluene	$C_7H_7NO_2$	137.1378	1.392	<0.1
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	$C_3H_6N_6O_6$	222.117	1.82	Insoluble

Compound Name	Chemical Formula	MW (g/mol)	Density (g/mL-20°C)	Solubility (g/100mL-20°C)
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)	$C_4H_8N_8O_8$	296.156	1.90	Insoluble
Tetryl	$C_7H_5N_5O_8$	287.1452		0.02
2,4,6-trinitrotoluene (TNT)	$C_7H_5N_3O_6$	227.133	1.64	0.01

Data for this table extracted from the NIST Chemistry Webbook, Cambridge Chemfinder and the Agency for Toxic Substances and Disease Registry internet resources.

2.2.4 Metals

Metals include any of the class of chemical elements of atomic number 20 and greater with metallic luster, ductility, and the ability to conduct heat and electricity. Although metals are naturally present in the Earth's crust, concentrated metal pollutants enter the environment in several ways, primarily though the burning of fossil fuels, as a result of mining and smelting activities, from the application of pesticides and fertilizers, and via sewage and municipal wastes. Metals in soils can exist as free ions, soluble complexes, bound to organics, precipitated or insoluble compounds (i.e. as oxides, carbonates, and hydroxides), or in silicate minerals (Salt, 1995).

Although small amounts of various metals are necessary for cell maintenance, metals can be toxic to both plants and animals in large amounts. Table 6 shows common metal pollutants and their health effects. Due to their prevalence, toxicity, and exposure potential, several of these metals are found in the top 20 on the 2003 CERCLA Priority List of Hazardous Substances, including arsenic (ranked first), lead (ranked second), mercury (ranked third), cadmium (ranked seventh), and chromium (ranked seventeenth) (CERCLA, 2003).

Traditional methods of mitigating metal contamination in soils include various isolation, extraction, immobilization, and toxicity reduction methods, including physical barrier (i.e. concrete, steel) isolation; chemical solidification/ stabilization; hydrocyclone, fluidized bed, or flotation processes; electrokinetic processes; soil washing; and pump-and-treat systems (Mulligan, 2001). Phytoremediation presents itself as a low-cost, solar-powered, environmentally-friendly alternative to methods such as extraction and pump and treat systems, which can be prohibitively expensive, and soil washing, which can reduce the fertility and bioactivity of soils (Datta, 2004). Because metals are generally non-biodegradable, phytoextraction is the most common mechanism of metals phytoremediation, although both phytovolatilization (i.e. for Hg, Se, As) and phytostabilization mechanisms occur. In general, metal uptake and phytoextraction coefficients decrease in the order Cr6+ > Cd2+ > Ni2+ > Zn2+ > Cu2+ > Pb2+ > Cr 3+ (EPA, 2000).

Although the first metal-hyperaccumulating plants were identified in the mid-1970s, this information has only recently been explored for purposes of remediation. A 1989 Baker review of terrestrial hyperaccumulators and a 2003 Reeves review of over 30 years' work on tropical hyperaccumulators by Robert Brooks and his colleague, catalogue many of the known species able to extract metals (including arsenic, cadmium, chromium, copper, cobalt, iron, manganese, nickel, lead, zinc). Yet despite the breadth of morphological/ geographical information now available for over 400 identified hyperaccumulator species, most plants are restricted to highly metaliferous, ultramafic (igneous, iron and magnesium-rich) soils and tropical environments, of relatively small biomass and slow-growing (Pulford, 2003). Additionally, not much is known about exploiting these properties for phytoremediation (Reeves, 2003).

The limits of these hyperaccumulator plants are apparent after a review of the very few field-scale metal phytoremediation successes, despite several years of intense efforts to find a magic phyto-bullet. Disappointing performance of lead phytoextraction was illustrated at the Fort Dix Superfund site, where the amount of lead removed was less than the uncertainty in the heterogeneous soil profile and less than the amount of unaccounted "missing" lead (Rock, 2003). Similarly, ineffectiveness of lead removal was concluded at the Magic Marker Superfund site, where lead concentrations in phytoextracted tissue did not account for the reduction in soil lead concentrations (Rock, 2003). These inefficacies have led to current research interests in identifying those genes responsible for metal resistance and accumulation and in developing enhanced transgenic plants for application in the field. Recently, Song (2003) explored the effect of inserting yeast proteins into mouse ear cress (*Arabidopsis thaliana)* and Gisbert (2003) investigated genetically-modified shrub tobacco (*Nicotiana glauca*), in two independent efforts to develop a lead and cadmium tolerant plant that may lead to better field success in the future.

One of the most important factors determining metal phytoremediation success is contaminant bioavailability. Metal bioavailability is determined by physical factors (contaminant coarseness, soil texture, etc.), chemical factors (concentration, speciation, pH, Eh, cation exchange capacity, acidity, redox potential), and biological factors (plant, mychorrizal, and microogranism activity) (Ernst, 1996). Some of these factors can be altered in the development of a phytoremediation site, such as importing more amenable soils, adjusting pH and/or alkalinity, etc. For example, decreasing soil pH generally increases metal availability, but it is important to make sure plants are able to survive under the same pH conditions. Competition between metals can also have a profound effect: in general, increasing the metal loading rate in a soil (i.e. containing cadmium, chromium, copper, manganese, lead, and zinc) decreases the bioconcentration factor of metals in plants. (Wang, et al 2002).

Table 6. Potential Human Health Effects of Metals

Metal	MW	Health Effect
Arsenic	74.92	Acute: Lung irritation, nausea, vomiting, blood vessel damage, abnormal hearth rhythm, death. Chronic: keratoses and skin effects; peripheral vascular disease; hypertension and cardiovascular disease; cancers of the bladder, kidney, liver, and lung; diabetes mellitus; possible neurological effects
Lead	207.20	Affects central nervous and reproductive system, damages kidneys, may cause anemia, decrease reaction time, cause weakness in fingers, wrists, ankles, and affect memory.
Mercury	200.59	Bronchitis, gingivitis, pulmonary edema, nervous system disorders, and permanent damage to brain, kidneys, and developing fetus.

Metal	MW	Health Effect
Cadmium	112.41	Pulmonary edema, emphysema, anemia, lung cancer, anosmia, kidney disease, fragile bones with long-term exposure. Acute exposure: lung damage, vomiting, diarrhea, and death
Chromium	52.00	Nosebleed, ulcers, stomach upsets, convulsions, kidney and liver damage, death. Cr (VI) is a carcinogen.
Zinc	65.39	Corneal ulceration, esophagus damage, pulmonary edema, skin irritation, stomach cramps, nausea, vomiting.
Nickel	58.69	Dermatitis, pneumonia, lung and nasal cancer, chronic bronchitis, effects on blood and kidneys. Probable carcinogen.
Silver	107.87	Blindness, skin lesions, pneumonoconiosis, arygria, lung irritation, stomach pains.
Copper	63.55	Acute: stomach and intestinal distress, liver and kidney damage, anemia. Chronic: headaches, dizziness, nausea, diarrhea.
Manganese	54.94	Liver cirrhosis, pneumonia, bronchitis, manganism, respiratory problems, sexual dysfunction

Data for this table extracted from the Cambridge Chemfinder and the Agency for Toxic Substances and Disease Registry internet resources.

Chlorinated solvents, pesticides, explosives and metals are only four of several major contaminants found at hazardous waste sites and only one of many site characteristics that define a site. The varying nature of what can be found at a site poses a challenge for determining whether phytoremediation is a viable remediation technology for any particular site. The next section of this document details considerations for determining whether phytoremediation is appropriate for a site.

3. IS PHYTOREMEDIATION RIGHT FOR YOUR PROJECT?

3.1 Site Characteristics

3.1.1 Site Characterization

A thorough site analysis that includes contaminant, geological, hydrological, and soil assessments is essential to determine base line conditions, phytotoxic conditions, the potential for contaminant removal, and to meet treatment goals (Tsao, 2003). The ITRC has produced Decision Tree documents (1999, 2001) to aid in the evaluation of a potential phytoremediation sites, although a brief overview of some important considerations can be found below.

3.1.1.1. Contaminant

As discussed previously, the nature of the contaminant (recalcitrance, persistence, bioavailability, etc.) is crucial when developing effective phytoremediation strategies for a given site. High contaminant concentrations may limit phytoremediation as a treatment option due to phytotoxicity or the impracticality of using such a slow remediation method. Additionally, the physical location of the contaminant will determine the efficacy of treatment. Due to plant root limitations, phytoremediation of soils and sediments is typically employed for contaminants in the near surface environment within the root zone. For groundwater treatment, phytoremediation is limited to unconfined aquifer where the water table and the contaminant are both within reach of plant roots (either in direct contact or via transpiration).

3.1.1.2. Site Area and Activities

Past, current, and future site activities will affect phytoremediation system design. Past site activities will determine contaminant and soil properties (i.e. quantity, age, and quality) at the site and existing vegetation may influence the growth and stability of any introduced phytoremediating plant species. An area assessment will be required to consider the amount of space available for phytoremediation, to identify any physical obstacles, and to accommodate any concurrent activities. Chemical, physical, and biological impacts of vegetation on the site should also be determined. Because phytoremediation is a long-term remediation process, often on the order of several years, any proposed future site activities will also need to be considered and integrated into the final system design.

3.1.1.3. Geological and Hydrological Conditions:

Topography of the site will affect surface and subsurface flow patterns and drainage. A proper evaluation of the hydrologic regime includes measuring recharge, potentiometric levels, and discharge, and includes a determination of surface and subsurface runoff, infiltration, and water storage. The remediation of groundwater requires creating a cone of depression so contaminants can be transported to the plant root zone for treatment. The goal of hydraulic control is to have plume movement minimized as much as possible, where infiltration is roughly equal to the amount of evapotranspiration. Runoff and infiltration controls are necessary to prevent contaminant mobilization. At sites with very porous soils, lining may be required to control the amount of infiltration. Calculating the overall water balance of the system may be required to estimate whether phytoremediation will be effective at controlling contaminant plumes. The use of hydrological models, such as the USGS groundwater model MODFLOW, can aid in the assessment and characterization of aquifer and contaminant movement. For example, site characterization and groundwater flow modeling using MODFLOW at the Aberdeen Proving Grounds found phytoremediation processes to be more effective than groundwater circulation wells in the control and removal of dissolved-phase volatile organic compound (VOC) plumes contaminating the site (Hirsh, 2003).

3.1.1.4. Soil Type

Soil characteristics, such as moisture content, available oxygen, organic matter content, cation exchange capacity, pH, alkalinity, content, texture (particle size), and temperature will have significant effects on contaminant mobility and fate. For example, metal bioavailability in high clay and low organic content soils is decreased. Higher soil cation exchange capacity indicates greater sorption of metal contaminants. Soil fertility will determine whether additional fertilizers will be necessary. Soil pH affects metal contaminant solubility as well as plant growth, and a balance should be met to maximize both. The importance of soil conditions was made apparent in a recent study by Boyle and Shann (1998), who compared the growth response of three different plant species (sunflower, Timothy grass, and red clover) under varying soil conditions (coarse silty loam, fine clay loam, and fine-silty loam) and found soil type to be one of the most significant factor in rhizosphere degradation of a pesticide (2,4,5-trichlorophenoxyacetic acid). Characterization studies to assess horizontal and vertical distributions of soil properties should be undertaken prior to full-scale implementation.

3.1.2 Climate

At the macro scale, climate is one of the major factors affecting evapotranspiration rates and, subsequently, the amount of contaminant that can be contained. Optimal conditions for maximum evapotranspiration are high water, high solar radiation, high wind speed, warm temperature, low relative humidity (high vapor pressure gradient), and long growing-season environments (Vose, 2003). Evapotranspiration is linearly related to precipitation and the amount of water available in the soil. Solar radiation regulates the opening and closing of the stomata and wind speed affects convective flow across leaf surface area. Relative humidity and vapor pressure gradients on the leaf surface will limit the amount of transpiration. Frost dates serve as limits to effective duration of a phytoremediation season for most plant species.

3.1.3 Time Constraints

Phytoremediation is a long-term remediation strategy, but the time required varies and is hard to predict. It requires sufficient time for vegetation to become established and grow to levels associated with higher transpiration rates. Phytoremediation is also limited by climate variation and seasonal effects particular to a site, which lengthen the overall time required. For example, perennial plants require at least a year to establish, and for organic compounds, at least three or more years are needed to allow for plant stabilization (Davis, 2003). A rough estimate of the clean-up time required can be extrapolated from calculating the rate of contaminant uptake by a plant. The uptake rate requires knowing the efficiency of uptake (i.e. transpiration stream concentration factor, TSCF), the transpiration rate, and the concentration of contaminant in soil solutions (Schnoor, 2003).

3.2 Plant Considerations

3.2.1 Plant Selection

Selection of appropriate plants should take into consideration issues of contaminant tolerances, evapotranspiration rates, climate and weather (e.g. flood, drought) tolerances, growing season, root depth, and disease and pest resistance. Although no plant protocols have been established, an integration of this database with others (such as the U.S. Department of Agriculture [USDA] plants database) can be used to narrow down the possibilities.

3.2.2 Types

Plants used in phytoremediation include trees, grasses, flowers, and shrubs, and various aquatic plants. Although nearly all the phytoremediation sites to date have used terrestrial plants, several hydroponic and aquatic plant studies have been employed for use in constructed wetlands and in plant/ phytotoxicity screening to determine the efficacy of contaminant uptake from groundwater under idealized conditions. Aquatic plants have great potential for *in situ* remediation, such as with the use of constructed wetland biofilters, however they are not considered any further here. Plant selection requires demonstrated effectiveness at mitigating the pollutant of concern and a phytotoxicity evaluation. A perusal of the phytoremediation database shows that the species most commonly used in field-scale phytoremediation applications are (hybrid) poplar, (hybrid) willow, cottonwoods, ryegrass, fescue, alfalfa, Indian mustard, and parrot feather. The popularity of hybrid poplars is due to their quick growth, deep roots, and extremely high rates of evapotranspiration. Poplars and other plants, however, vary considerably across their genus in their phytoremediating abilities (i.e. growth rate, metabolic activity, rooting characteristics, disease and drought resistance, etc.), so care should be taken when selecting cultivars that have worked at a site with differing characteristics (Compton, 2003; White, 2003). For heavy metals, accumulator plants typically selected are not only able to tolerate and accumulate pollutants, but also have high above-and-below-ground biomass and are fast growing; however, Pulford (2003) proposes using non-accumulator plant species for heavy metal uptake in arrangement with optimized soil conditions (i.e. chelation) or via genetically-modified strains. For organics, vegetation should generally be fast growing, have high evapotranspiration rates, and transform contaminants to less toxic or nontoxic forms (ITRC, 1999). For remediation of chlorinated solvents, typically used species include hybrid poplar and hybrid willow (see database). For munitions, periwinkle (*Catharanthus roseus*) has been successful for munitions, in addition to the parrot feather (*Myriophyllum aquaticum*), although hybrid poplar is beginning to emerge as an alternative (Hughes, 1997; Bhadra, 1999; Wayment, 1999). Pesticides are most commonly treated using hybrid poplars, although various other crop, grass, and colonizing plant species have shown tolerance and phytoremediating potential in the laboratory, as summarized by Karthukeyan *et. al* (2004).

3.2.3. Phytotoxicity and Treatability Evaluation

Toxicity screening tests are use to determine possible plants for a set of contaminant, nutrient levels, pH, and salinity conditions. Using these bench-scale pot, hydroponic, or greenhouse studies is a prerequisite to actual implementation at a contaminated site. When evaluating plants in phytotoxicity studies, a general rule to follow for organic contaminants is that plants able to survive 10+ mg/L of organic contaminant are recommended, with plants surviving 1-10 mg/L conditions as additional possibilities; for inorganic contaminants, species able to tolerate 100+ mg/L are recommended, with plants surviving at 10-100 mg/L as additional possibilities (Gatliff, 2004). Treatability studies are used to estimate the rate of contaminant treatment, to determine fate and transport in the system, and to develop models and mass balances. In treatability studies under controlled conditions, it is imperative to replicate site conditions (site soils, humidity/ water availability, pH, etc.) as closely as possible. A review of the genetic and molecular basis of plant tolerance and phytotoxicity was recently undertaken, with special attention to chlorinated aliphatic compounds and explosives (Medina, 2003). Karthikeyan *et al* (2004) recently reviewed the laboratory-scale tolerances of various tree, grass, and crop species to various pesticide compounds.

3.2.4. Root and Rhizosphere

Roots have a variety of functions that include structural support for plants, the uptake of nutrients and water, and the release of exudates. For phytoremediation, treatment is limited to the roots' zone of influence and therefore the contaminant depth should not exceed root depth. For non-woody plants, the effective root depth usually does not extend more than a couple feet; however, for phreatophytes (i.e. poplar trees) this depth can be extended significantly by methods of deep rooting. Root exudates also play a crucial role in rhizosphere phytoremediation processes for both inorganic and organic contaminants.

Exudates are compounds released from plant roots that stimulate microbial growth and activity in the rhizosphere. Exudates can also alter soil pH, act as chelating agents, aid in nutrient recomplex with metals, and degrade organic compounds (Tsao, 2003). Root turnover is yet another mechanism of adding organic substrate to soils for the stimulation of microorganisms. Although rhizosphere processes are generally poorly understood, several plant species (e.g. legumes) are capable of sustaining active microbial populations, and may be selective in their capacity to degrade certain compounds, such as pesticides (Karthikeyan, 2004).

Root growth in the contaminant zone is a function of contaminant and water depths, climate, nutrient availability, water distribution, soil strength, and available oxygen (Negri, 2004). A few recent studies illustrate the importance of these factors. For example, Nzengung (2004) observed that available oxygen, nutrients (nitrate), root mortality, and redox conditions determined whether rhizodegradation of perchlorate in the root-zone was the favored phytoremediation mechanism. A 2003 study by Keller that compared the ability of various plant species to extract copper, zinc, and cadmium from soils found that a larger ratio of root density to above-ground biomass and generally large overall root area were positive factors. Modulating root temperature by the use of polyethylene mulches for enhancing cadmium and zinc extraction in potato plants was proposed by Baghour (2002).

3.2.5 Planting Methods

The method of planting will depend on the type of vegetation used in treatment. For example, grasses are usually dispersed as seeds, and trees such as poplar are transplanted from pots as whips or from cuttings. Planting dates are dependent on the climate at a given site. Seeding methods including depth of sowing, then “pelletizing” of smaller seeds, hand vs. machine sowing, density and distance between rows have been discussed in the literature (Angle, 2001). Typically, vegetation is planted at the leading edge of the contaminant plume, perpendicular to groundwater flow (Ferro, et. al 2003).

If deep rooting is required, poplars and willows are popular phreatophyte choices due to their natural predisposition to develop roots at greater depths, especially in porous soils and arid environments. Rooting below 1 meter usually involves installation in boreholes or trenches, along with engineered media to direct the root growth. Deep rooting can be feasibly engineered to depths of up to 40 feet. Engineered media includes backfill material to maintain favorable root growth conditions, and casings to direct root growth and reduce the amount of surface water available, as well as short-circuiting, in the system (Negri, 2003). Deep rooting may not always have desired effects. For example, Sung (2003) found that rooting at depth made no difference in TNT or PBB disappearance rates for Johnsongrass (*Sorghum halapense*) and Canadian wild rye (*Elymus canadensis*). Additionally, care should be taken to ensure there is a sufficient lateral root system to maintain structural support.

3.2.6 Native versus Non-native Species

Recent legislation, such as two recent Executive Orders (1994, 1999) and the 1996 Invasive Species Act and the 2000 Plant Protection Act, limit the introduction of invasive or non-native plant species to areas where they are not indigenous. In addition to regulatory reasons, indigenous species are recommended over non-native species for use in phytoremediation projects as they involve the least amount of human and ecological risk. Native species are often better adapted to the conditions of the environment (i.e. adapted to soil conditions and are tolerant to the hydraulic regime), require less maintenance, monitoring, and control, have lower energy requirements, and involve less residual disposal (Marmiroli, 2003; Compton, 2003). The hierarchy for selecting plants is native species > hybrid species > non-native/ introduced species > engineered species (ITRC, 2004).

3.2.7 Plant Specificity
Although most phytoremediation sites are developed assuming a rigid plant-contaminant specificity, there have been some interesting developments in studies on plants that are able to remediate more than one class of pollutant. For example, a field plot study by Mattina *et al* (2003), determined concurrent uptake of chlordane and heavy metals (As, Cd, Pb, Zn) by Zucchini (Cucurbita pepo) and spinach (Spinachia oleracea). The possibility of one plant remediating multiple categories of contaminant should be accounted for in project design to ensure that remediation objectives are met.

3.2.8 Transgenics
Genetic modification of a plant involves insertion of a piece of foreign DNA (e.g. for enhanced tolerance or accumulation) into the genome of the species of interest. Wolfe and Bjornstad (2002) hypothesize that phytoremediation using genetically-engineered plants would create more opposition and controversy than non-genetically engineered plants based on past public responses to the biotechnology applications.
The negative perceptions and widespread resistance to the use of genetically-engineered plants can be attributed to "the failure of the biotechnology industry to educate the community about the risks and benefits of transgenic technology," which Linacre (2003) suggests can be overcome by adopting a combined risk assessment (i.e. defining risks, associated probabilities, and dose/consequences), risk management, and risk communication strategy.

Despite the aforementioned social obstacles, research into transgenic plants has accelerated and modified, phytoremediating plants have been introduced at field-scale. While most past transgenic research has focused on developing hyperaccumulators or plants with enhanced biodegradation, some recent research has been undertaken to develop genes for "anti-contaminant/antibody fragments" capable of improved pollutant-accumulation (Chaudhry, 2002).

Genetically-modified lead accumulators were previously discussed, but a sampling of some recent GMO (genetically-modified organism) research follows: Transgenic mouse ear cress (Arabidopsis thaliana) has recently shown to hyperaccumulate arsenic in laboratory studies (Dhankher et. al, 2002). And in October 2003, the first commercial application of genetically modified species for phytoremediation was planted at a Danbury, CT brownfields site. In this particular case, bacterial genes that encode enzymes for conversion of toxic methyl mercury to volatile elemental mercury were inserted into cottonwood trees (APGEN, 2003).

3.3 Agronomic Considerations

3.3.1. Plant Age and Metabolic Status

While water content, diurnal cycles, temperature, and periods of dormancy are also important to determine metabolic status, frost dates for a given site is one of the largest determining factors (see database). Plant age determines plant size and overall leaf surface area, which in turn is responsible for evapotranspiration rates. For example, poplar transpiration rates are around 1.6-10 gallons per day (gpd) during the first two years, but transpiration rates increases to between 13-200 gpd after 10 years (ITRC, 2004). Plant age also determines contaminant tolerance; for example, in a study by Peralta-Videa (2003), the phytotoxicity of metals (i.e. Cd, Cu, Zn) to alfalfa plants decreased with plant age. Deciduous trees are dormant for a large part of year, while conifers continue to transpire at a reduced rate throughout the winter season and have higher overall rates of evapotranspiration due to higher total leaf surface area (Vose, 2003).

3.3.2. Amendments

The addition of inorganic, organic, and bio-amendments are often used to enhance phytoremediation, and there are a few recent applications of these to pesticides. Microbe-mediated rhizosphere degradation is a principal phytoremediation mechanism, and often the major limiting factor of pesticide biodegradation is a deficient population of microorganisms (Olson, 2003). One recent study showed that bacterial (*Actinomycete*) inoculants in soils increased the amount of 1,4-dioxane in soil that was mineralized, although their addition had little effect on the total amount of dioxane removed by hybrid poplars (Kelley *et al*, 2000). Laboratory studies have also shown that strains of *Agrobacterium tumefaciens* were capable of increasing root mass and stimulating PCB uptake by plants, an amendment method which may be applicable to pesticide remediation in the future (Chaudhry, 2002; Gleba, 1999).

Similarly, metal phytoextraction can be used as part of a treatment train or in combination with other remediation technologies. Popular alternatives include the addition of chelating agents such as EDTA, or organic acids such as citric acid that mimic natural plant excretion of organic ligands (Romkens, 2002). However, care must be taken when adding chelates and other amendments, because they may lead to uncontrolled releases and/or require costly engineered barriers to be put in place (Rock, 2003). Amendments should be evaluated in bench-scale studies prior to field application to ascertain optimum conditions. For example, citric acid may be degraded by microorganisms too quickly to be used in long-term remediation (Romkens, 2002), or the increased metal bioavailability with addition of EDTA and citric acid amendments may correspond to high levels of plant phytotoxicity (Chen, 2001; Turget, 2004). Adding biological amendments such as fungi and microorganisms, or integrating phytoremediation with another technology (e.g. electrokinetic remediation) is another possibility.

3.3.3. Other Agronomic Issues

Although monoculture plantations have often been used in phytoremediation in the past, there is increasing trend towards incorporating mixed cultures. Monoculture plantations have the advantage of reduced competition for nutrients and space, and it may be easier to control undesirable organisms that do emerge. However, the use of a single plant species introduces several potential problems. Intensive monoculture cultivation requires high levels of irrigation, fertilizer, and amendments to sustain plant productivity. Monocultures are far less resistant to disease and invasive species than mixed cultures. Additionally, optimization of some phytomechanisms, such as rhizodegradation, requires a diverse and complex range of species interactions, which cannot occur under a single plant environment (Olson, 2003). If a mixed culture is used, the potential for alleopathy or interspecies competition between plants, which may lead to the subsequent inhibition of one plant, should be evaluated.

Plant rotation is commonly used in agronomic practices to recycle important nutrients in the soils, reduce the need for fertilizer and other amendments, and to alleviate stresses. Natural succession often results as an ecological community response to environmental stresses. Site operators may consider mimicking succession by first introducing a "pioneer" species to stabilize conditions, then adding a more and more diverse mix of plant species with time, improving disease and stress resistance (Olson, 2003). Additional agronomic recommendations include avoiding a grid pattern when planting, allowing for sufficient space between trees (for maintenance and monitoring activities), and installing monitoring equipment, drainage systems, etc. prior to planting (Compton, 2003).

3.4 Regulatory Considerations

Phytoremediation as a technology has experienced increased regulatory approval and standardization, although there are no federal regulations specific to phytoremediation to date. Regulations posed by the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response Compensation and Liability Act (CERCLA), Clean Air Act (CAA), Toxic Substances Control Act (TSCA), Federal Insecticide Fungicide and Rodenticide Act (FIFRA), Federal Food Drug and Cosmetic Act (FFDCA), Invasive Species Act, Plant Protection Act, statutes enforced by the USDA and state statutes must all be upheld when installing a phytoremediation system. USDA and state statues may govern the plant species used and the extent of vegetation allowed and/or required. Common issues faced under these regulations include:

- Transport of contaminants from the subsurface to the surface.
- Transport of contaminated media off-site
- Permits to dig on-site
- Permits to plant
- Handling of secondary waste/degradation products

Site managers must ensure all actions abide by the stipulated regulations and that proper permits are obtained.

3.5 Ecological and Social Considerations

It is obvious that success of a phytoremediation project is dependent on various technical aspects such as site, contaminant, and plant characterizations; equally imperative, yet less often considered, are numerous social considerations. Some issues that may affect community acceptability of phytoremediation include site aesthetics, odor production (i.e. with volatile contaminants), dust from tilling and maintenance, pest attraction, and production of pollen (i.e. aggravation of allergies). Additional issues may include the degree of perceived risk (i.e. contaminant concentrations and required length of treatment); unpredictability (i.e. the dearth of available data and research on this "emerging" technology); issues of genetic engineering; ecological impacts; the appropriateness of extrapolating demonstration to full-scale; and linking, or including as a part of a treatment train, phytoremediation to other, less acceptable technologies or practices. (Wolfe and Bjornstad, 2002).

There are several ecological concerns to be cognizant of when developing a phytoremediation site. As discussed previously, introduced species can become invasive if not controlled properly. Introduced and genetically-modified species can have possibly deleterious effects on nearby crops if interbreeding between species or cross pollination is allowed to occur. Monoculture plantations maybe more susceptible to disease, increasing the possibility of airborne plant diseases that may infect other ecological communities. Additionally, without proper pest and animal controls in place, bioaccumulated contaminants in vegetation may be enter the food chain.

Despite the aforementioned concerns, phytoremediation is generally regarded in a favorable manner because it is a solar-driven "green" technology that concurrently treats contaminants *in situ* and improves the aesthetics and habitat of the surrounding area.

3.6 Operation and Maintenance

Because phytoremediation uses living organisms, installations of the technology have unique O&M requirements when compared to other more traditional remediation systems. Maintaining a healthy system is crucial to the continuation and effectiveness of the remediation process. Varying plants, climates, and contaminants may cause a site to have some of, all of, or additional requirements to those listed here. Some unique operation and maintenance requirements for a phytoremediation site include:

- Visual inspections
- Fertilization
- Irrigation
- Weed control
- Mowing
- Harvesting
- Pest Control
- Replanting

Visual inspections, fertilization, irrigation and pest control are steps taken to ensure plant growth. Weed control aids in both plant growth and prevention of invasive species infiltration. Mowing is primarily implemented to facilitate easier monitoring and maintenance of the site. Harvesting plant tissue removes contaminants that have accumulated within the plant tissue. This storage of contaminants can be either a liability or an asset to a phytoremediation site. If the contaminant is a hazardous waste with no further use, the tissue must be disposed of as hazardous waste at an additional cost. Some contaminants accumulated in the plant tissue, such as heavy metals, may be reclaimed and sold in a practice known as phytomining. In such cases, these "cash crops" can be an asset to the project by defraying some of the total cost. Pest control is important to protect both the livelihood of the vegetation and also of the surrounding wildlife. Animals that eat or damage the vegetation can destroy plantations, thereby hindering remediation, but they can also harm themselves if they ingest contaminated plant tissue or water. Replanting is a maintenance issue necessary to ensure continuous contaminant uptake. Vegetation dies for several reasons (i.e. damage by animals, insects and weather) and needs to be replanted to maintain the root mass necessary for contaminant uptake and release of exudates. Dead plant matter, along with other debris, must be removed from the site. Site cleanup is a maintenance issue that helps facilitate easy monitoring and implementation of other maintenance needs. Vigilance, frequent site visitation, and maintenance during first year of a plantation is crucial and play a large factor in whether phytoremediating plants become established or not, with moisture availability and weed control being some of the more critical requirements (Compton, 2003).

3.7 Performance Monitoring

Some monitoring requirements for a phytoremediation system are similar to those of a traditional remediation system, such as contaminant concentration and groundwater levels. Phytoremediation installations also have unique characteristics that require monitoring. They include:

- Plant health
- Root depth and density
- Evapotranspiration
- Groundwater levels
- Tissue sampling
- Precipitation
- Soil moisture
- Microbial characterization

Plant health and root depth and density must be monitored to ensure continuous contaminant uptake and remediation in the target zone. Evapotranspiration and groundwater level monitoring, along with tissue sampling, can aid in confirming contaminant uptake and hydraulic control. Precipitation, soil moisture and microbial characterizations are monitored to classify the environment the system is operating in. This classification is important for two reasons. Firstly, data collected can be consulted when failures occur to aid in the determination of the cause. Notable changes in aspects of the environment can be investigated as possible remedies to the failure. Secondly, characterization of the climate is important to thoroughly document successful applications of phytoremediation. The varying nature of site characteristics suggests there is not one installation to be prescribed for all sites. Therefore, each site will have different monitoring requirements.

The site-specific nature of a phytoremediation prescription lends itself towards a need for thorough documentation of site installations. Experts in the field have given opinions about the kind of data that should be collected from each site in order for a phytoremediation database to be useful. The resulting compilation of phytoremediation sites has been organized into a database for easy navigation and implementation into searchable software programs if needed.

4. DATABASE

4.1 General Layout

The database is divided into four sections, one for each major contaminant class: chlorinated solvents, pesticides, explosives, and metals. Appendix A contains site contaminated with chlorinated solvents, Appendix B contains pesticide sites, Appendix C contains explosives sites, and Appendix D contains metals sites. Each appendix contains, at the beginning, a table of contents for every listed individual contaminant that details what sites contain what contaminant. In the pages following the table of contents, the data collected for each site have been compiled and are presented in a single page layout.

4.2 Soil and Climate Characterizations

In order to maintain uniformity for the entries in the database, a single classification system was necessary to define soil and climate characteristics. The need for a single system to be used in this database resulted in an extensive search and the eventual selection of one classification system. The USDA 1993 Soil Survey Manual was used for soil texture classification, because it contained a manageable range of classification terms. Others soil classification systems had too many or too few categories to sufficiently characterize soil. In addition, soil texture classes used in the USDA Manual were identical to those found in a majority of the existing site literature. The soil texture categories, containing a brief description, are listed in Appendix E.

Following a review of the available site data and consultation with experts, the critical climate parameters necessary for phytoremediation site determination were defined. These parameters include site average temperature ranges, elevation, average annual precipitation, and frost dates (growing season). The National Oceanic and Atmospheric Association (NOAA) Cooperative Institute for Research in Environmental Sciences (CIRES) Climate Diagnostics Center was the resource used to obtain temperature, elevation and precipitation data. The primary factor in this decision was the availability of multiple criteria from one source. Frost date data was taken from the Victory Seeds.com website because of its ease of use and its reliable source of information. Victory Seeds data comes from the *Climatography of the U.S.* No. 20, Supplement No. 1 document released in 1988 by the National Climatic Data Center, NOAA, and the U.S. Department of Commerce.

When information for a particular site location was not available, data was taken from the closest city containing all the existing parameters. A representative list of cities across the United States, including the four critical climate parameters, can be found in Appendix F.

5. CONCLUSION

5.1 Summary

A summary of findings for each of the four contaminant classes, including the number of field-scale sites, typical contaminants, most commonly planted species, and cost range of site implementation and operation, is provided below.

5.1.1 Chlorinated Solvents

Appendix A contains 47 sites that have used phytoremediation to treat chlorinated solvents. The most common contaminants found at these sites are trichloroethene and perchloroethene. Hybrid poplar and phragmites are the typical plant species used in treatment. Total costs for installation, operation, and maintenance of these phytoremediation sites vary widely, from about $51,000 to $2.1 million per site. The higher costs associated with some of these sites generally reflect pilot or demonstration sites where extensive research operations and/or monitoring and are included as part of the total cost.

5.1.2 Pesticides

Appendix B contains 19 sites for the phytoremediation of pesticides and herbicides. The most commonly remediated contaminants are atrazine and alachlor. Hybrid poplars are the most popular vegetation used in treatment. Costs for pesticide phytoremediation range between $6,000 and $5.4 million/acre, where the higher costs reflect pilot or demonstration sites.

5.1.3 Explosives

Appendix C contains 12 field-scale sites that were used to remediate explosives. The most common explosive contaminants found at these sites are HMX (octahydrotetranitrotetrazocine), TNT (trinitrotoluene), and RDX (hexahydrotrinitrotriazine). Tobacco composting and constructed wetlands are most typically applied in treatment. Total costs for installation, operation, and maintenance of these sites vary between $60,000 and $1.8 million.

5.1.4 Metals

Appendix D contains 44 sites for the remediation of metals and metalloids. The most commonly remediated metals are lead (in the past projects), and arsenic and mercury (currently). Metal-specific hyperaccumulator plants and poplars are most often planted to remediate metals contaminated sites. The cost of phytoremediation for these sites ranges between $5000 and $4 million per acre.

Referring to the compiled data, it can be deduced that no single application of phytoremediation is appropriate for all sites. Rather, a prescription must be made based on a thorough site assessment. Phytoremediation may be the sole solution to a remediation project in instances where time to completion is not a pressing issue. While phytoremediation may not be a stand alone solution to all hazardous waste sites, it can certainly be used as part of a treatment train for site remediation either during peak growing seasons or as a polishing step to clean up the last remaining "hard to get" low concentrations.

Phytoremediation is still a new technology looking for industry-wide acceptance. The number of field sites collected in this project indicates it has received greater acceptance for chlorinated solvents and metals while just starting to gain acceptance within the explosives and pesticides domains. Continued bench-scale studies are needed to determine plant toxicities, degradation pathways and contaminant fates and the resulting field scale applications are necessary to provide proof the technology works in order for phytoremediation to be fully accepted by the industry.

5.2 Outlook

The data compiled in this project may have a future as part of a larger database. EPA Region 5 and EnviroCanada are currently working on similar data compilation projects. EPA Region 5 is focusing on field sites applying phytoremediation to remediate radionuclides and EnviroCanada is focusing on total petroleum hydrocarbon (TPH) sites. Together, the three data sets will address six of the seven major contaminant groups, leaving only non-halogenated organics to be addressed.

Though plans have not been thoroughly investigated or confirmed, there is a possibility that the data collected in this project will be incorporated into a searchable software program for easier use and navigation in the future.

PHYTOREMEDIATION FIELD STUDIES DATABASE for CHLORINATED SOLVENTS, PESTICIDES, EXPLOSIVES, and METALS

Appendices

Appendix A: Chlorinated Solvents Database

Table of Contents

PCE = Perchloroethene
TCE = Trichloroethene
DCE = Dichloroethene

TCA = Trichloromethane
DCA = Dichloromethane
PCA = Perchloromethane

DCM = Dichloromethane
VC = Vinyl Chloride
CT = Carbon Tetrachloride

CF = Chloroform
PCB'S = Polychlorinated Biphenols
PCDF = Polychlorinated dibenzofurans

Site Name	Aberdeen Proving Grounds J-Field
Site Location	Edgewood, MD
Contaminant	1,1,2,2-Perchloroethane, 1,1,2-Trichloroethane, Perchloroethylene, Trichloroethylene, Dichloroethylene, 1,2-Dichloroethane, Vinyl Chloride
Vegetation Type	Hybrid Poplar, Sweet gum, -Silver Maple, Magnolia trees(1996)
Planting Descriptions	184-2 yr old hybrid poplars planted 2-6' bgs. Surficial drainage installed to remove precipitation quickly to allow roots to reach GW
Media Type	Groundwater, Soil: tight soils, silty sand
Site Characterizations	GW 0.3-2.5m bgs. Laterally continuous layer of clay prevents contamination moving deeper than 8'
Evapotranspiration Rates	Tree uptake is 1,091gpd, expected 1,999gpd after 30 yrs growth.
Climate	Temp. range: -7 to105; Elev: 148 ft; Mean annual precip: 105"; Growing season: 4/11 to 10/29
Mechanism	Phytodegradation, Hydraulic Control
Operation/Maintenance Requirements	Insect Control, animal control, mowing
Project Scale	Full Scale - 1 acre
Project Status	Operational/In Progress. Planted April 1996
Cost	Tree: $80 each Prep: $5,000 UXO Clearance: $80,000 OM: $30,000
Funding source	DoD Lead, Federal Oversight
Initial concentrations	up to 260ppm
Final Concentrations	No reduction in concentrations. Continuous source.
Lessons Learned	
Comments	TCE was detected in leaf tissue during the first year of the project. A transect of monitoring wells has been used to evaluate the program's effect on groundwater and has shown significant hydraulic effects by the trees. GW sampling indicates contaminants have not moved off site.
Primary Contact	Steven Hirsh, US EPA (215) 566-3352 hirsh.steven@epa.gov
Citation	Phytotransformation Groundwater Capture on 1 Acre Plot, Phytoremediation: Technology Evaluation Report. GWRTAC TE-98-01 (p 8)

Site Name	Altus Air Force Base, Oklahoma
Site Location	Altus AFB, OK
Contaminant	TCE, cis-1,2-DCE, PCE
Vegetation Type	*Populus x Canadensis Nor'easter* trees
Planting Descriptions	109 10-gallon trees
Media Type	
Site Characterizations	GW 5-8' bgs
Evapotranspiration Rates	
Climate	Temp. range: -8 to 110; Elev: 1280; Mean Annual Precip: 33.3"; Growing season: 4/15-10/16
Mechanism	Hydraulic control
Operation/Maintenance Requirements	
Project Scale	0.3 acre Demonstration
Project Status	Planted 3/1999
Cost	
Funding source	AFCEE
Initial concentrations	TCE (2-1,400 ug/l), cis-1,2-DCE (1-540 ug/l), PCE (2-1,200 ug/l)
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Rafael Vazquez, AFCEE (210) 536-1431 rafael.vazquez@brooks.af.mil
Citation	Work Plan for the Phytostabilization of Chlorinated Solvents from Groundwater at Site 2, Altus Air Base, Oklahoma, NTIS: ADA381406, 1999

Site Name	Amboer Road
Site Location	Milwauki, OR
Contaminant	PCE, degradation pdts
Vegetation Type	Hybrid Poplar
Planting Descriptions	
Media Type	Groundwater, Soil
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp. Range: 6 to 107 F; Elev: 33 ft; Mean Annual Precip: 36.3"; Growing season: 4/16-10/18
Mechanism	Phytoextraction, phytodegradation
Operation/Maintenance Requirements	
Project Scale	Field Demonstration (pilot), 5 acres
Project Status	Operational/In Progress
Cost	~ $120K
Funding source	
Initial concentrations	PCE, degradation pdts, 1ppm - 50ppb in groundwater, 100ppm in soil
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Lee Newman, U of SC (803)777-4795, Newman2@gwm.sc.edu
Citation	

Site Name	Anonymous
Site Location	Tacoma, WA
Contaminant	TCE, CCl4, PCE
Vegetation Type	Populus trichocarpa x P. deltoides
Planting Descriptions	Whips hand planted. Ammonium nitrate used
Media Type	Soil: Sandy loam
Site Characterizations	GW 11+' bgs
Evapotranspiration Rates	
Climate	Temp. range: -8 to 104; Elev: 36 ft; Mean annual precip.: 50.5", Growing season: 5/17 to 9/30
Mechanism	Phytoextraction
Operation/Maintenance Requirements	Fertilization, irrigation
Project Scale	Field demonstration, 1200 sq yd
Project Status	Jun-96
Cost	$1,000,000
Funding source	
Initial concentrations	TCE, CCl4, PCE
Final Concentrations	
Lessons Learned	
Comments	Most plants thrived. Contaminants added at 15-20 mg/l and removed in surplus water.
Primary Contact	Milton P. Gordon, U of WA (206) 543-1769, miltong@u.washington.edu
Citation	L. A. Newman et al. Remediation of trichloroethylene in an artificial aquifer with trees: A controlled field study Environ. Sci. Technol. 33:2257-2285 (1999)

Site Name	Argonne National Laboratory: 317/319 Area
Site Location	Lemont, IL
Contaminant	Perchloroethene, Trichloroethene, Carbon Tetrachloride, Chloroform, Zinc, Lead, Arsenic, Tritium
Vegetation Type	Eastern gamagrass, Hybrid Poplar, Golden Weeping Willow, Hybrid Prairie Cascade Willow, Laurel-leaved willow
Planting Descriptions	800 whips planted. 420 poplars installed in deep, lined boreholes (TreeWells®) 389 willows and poplars planted at or near surface. Used patented TreeWells® and TreeMediation® (Applied Natural Sciences Inc)
Media Type	Groundwater, Soil: Top-Bottom: 10' silty clay, 2' shallow aquifer, 8' silty clay, 10' silt/sand/silty clay deep aquifer
Site Characterizations	Groundwater 25-30' bgs, aquifer 5'
Evapotranspiration Rates	
Climate	
Mechanism	Phytostabilization, phytoextraction, phytodegradation, rhizodegradation
Operation/Maintenance Requirements	Fertilization, replanting, and significant Health/Safety expenditures because of radiological and other concerns
Project Scale	Full-scale (4 acres)
Project Status	Ongoing (planted 1999)
Cost	$1.2M
Funding source	US DOE
Initial concentrations	n/a; varies considerably throughout site, from ppb to ppm
Final Concentrations	n/a; varies considerably throughout site, from ppb to ppm
Lessons Learned	TreeWells® installed in effort to achieve hydraulic control
Comments	TCE and PCE and breakdown products (trichloroacetic acid) were detected in branch tissue of trees planted in contaminated soil in less than a year. TCE and PCE present in trees down gradient of plume after 2 yrs.
Primary Contact	Cristina Negri, Argonne National Laboratory (630) 252-9662 negri@anl.gov Ed Gatliff, Applied Natural Sciences (513) 895-6061 ans@fuse.net
Citation	Negri, M.C., et al 2003 Root Development and Rooting at Depths, in S.C. McCutcheon and J.L. Schnoor, eds., Phytoremediation: Transformation and Control of Contaminants: Hoboken, NJ, John Wiley & Sons, Inc. p233-262, 912-913 Quinn, J.J., et al 200 Predicting the Effect of Deep-Rooted Hybrid Poplars on the Groundwater Flow System at a Phytoremediation Site: International Journal of Phytoremediation, vol. 3, no. 1, p. 41-60

Site Name	Ashland, Inc.
Site Location	Milwaukee, WI
Contaminant	Dichloroethene, Perchloroethene, Trichloroethene, Benzene, Toluene, Ethyl benzene, Xylene, gasoline and diesel-range organics
Vegetation Type	Hybrid poplar trees, under story grasses
Planting Descriptions	485 trees planted
Media Type	Groundwater, soil: Fill soil, concrete and rock
Site Characterizations	GW 10' bgs
Evapotranspiration Rates	
Climate	Temp. range: -26 to 103; Elev.: 672 ft; Mean annual precip.: 34"; Growing season: 5/20-9/26
Mechanism	Phytoextraction, rhizodegradation, hydraulic control
Operation/Maintenance Requirements	Mowing, weeding, composting, insecticide
Project Scale	Full-scale, 0.4 acres
Project Status	Active. Planted in May 2000
Cost	$80,000
Funding source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Tree survival = 88% initially, 99% after replanting phytotoxic areas. Trees have tripled in height since planting. Roots observed at 10' depth during first growing season. Subsurface aeration has increased soil oxygen levels from 5% to 15%.
Primary Contact	Jim Vondracek, RMT (614) 790-6146 jevondracek@ashland.com
Citation	McLinn, E., Vondracek, J., and E. Aitchison. 2001. "Monitoring Remediation with Trembling Leaves: Assessing the Effectiveness of a Full-Scale Phytoremediation System". In: A. Leeson, E. Foote, M. Banks, and V. Magar (eds.) Phytoremediation, Wetlands, and Sediments, p121-127. Battelle Press, Columbus, Ohio.

Site Name	ATK Thiokol
Site Location	Elkton, MD
Contaminant	Chlorinated VOCs, TCA, TCA
Vegetation Type	TCA 25-26ppm, TCE 170ppb
Planting Descriptions	
Media Type	Willows
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp. Range: -14 to 102; Elev.: 36 ft; Mean annual precip.: 40.8"; Growing season: 4/25-10/15
Mechanism	
Operation/Maintenance Requirements	
Project Scale	
Project Status	
Cost	
Funding source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	No recent monitoring of concentrations
Citation	Dave Gosen, Alliant Tec Systems (952) 351-2664 dave.gosen@atk.com

Site Name	Bofors-Nobel Superfund Site
Site Location	Muskegon, MI
Contaminant	3,3 Dichlorobenzidine, vinyl chloride, Perchloroethene, Aniline, Azobenzene, Benzidine, 3,3 Dichlorobenzidine Toluene
Vegetation Type	hybrid poplar
Planting Descriptions	
Media Type	Groundwater, soil
Site Characterizations	GW 6' bgs
Evapotranspiration Rates	
Climate	Temp. Range: -15 to 99; Elev.: 644; Mean annual precip.: 32.6"; Growing season: 5/24-9/24
Mechanism	Rhizodegradation, phytoextraction, phytodegradation
Operation/Maintenance Requirements	cutting down any tree species that does not survive in the contained area
Project Scale	Pilot scale. Approximately 20 acres of planted tree species, with another (approx.) 20 acres of engineered treatment wetlands.
Project Status	On hold. Planted 6/2004
Cost	Estimated total remedy cost can be from about $ 15 million up to $ 30 million.
Funding source	PRP, Federal/State overview
Initial concentrations	Up to 3000-10000 ppm for halogenated and nonh semi vol
Final Concentrations	
Lessons Learned	
Comments	Phytoremediation is not the main goal of the remedy. The main goal is containment using the underground barrier (slurry) wall, with phyto as an enhancement.
Primary Contact	John Fagiolo, USEPA (312) 886.0800 fagiolo.john@epa.gov Ari Ferro, Phytokinetics (435) 750-0985 ariferro@phytokinetics.com
Citation	

Site Name	Carswell Naval Air Station (NAS) Golf Club
Site Location	Fort Worth, TX
Contaminant	TCE, cis-1,2 DCE
Vegetation Type	*Eastern Cottonwood (Populus Deltoides)*
Planting Descriptions	660 - whips and 2.5-3.8 caliper trees. Planting long side perpendicular to GW flow.
Media Type	Groundwater, soil: medium sand
Site Characterizations	GW 2.5-4m bgs, Aquifer thickness= 0.5-1.5m, K=6m/day, η=.25
Evapotranspiration Rates	Whips: 2.4(Jun) - 0.42(Oct) gal/tree-day Calipers: 3.89(Jul) -0.24(Oct) gal/tree-day
Climate	Subhumid. Temp Range: -1 to 113; Elev.: 574; Mean annual precip.: 33.7"; Growing season: 4/8-10/24
Mechanism	Phytodegradation Hydraulic control
Operation/Maintenance Requirements	Irrigation, fertilization, mulching
Project Scale	0.5 acre Field Demonstration
Project Status	8/1996 - 2001
Cost	$8/5-gal tree, 29 wells (surveying, drilling, testing) - $200,000; biomass - $60,000.
Funding source	USAF, DoD's ESTCP, EPA's SITE
Initial concentrations	Avgs on 12/1996: TCE = 610 µg/L, cis-1,2-DCE = 130 µg/L, trans-1,2-DCE = 4 µg/L
Final Concentrations	Avgs on 7/1997: TCE = 550 µg/L, cis-1,2-DCE = 170 µg/L, trans-1,2-DCE = 4 µg/L
Lessons Learned	No hydraulic control was observed during dormant season from Nov-Mar
Comments	Although TCE conc. did not decrease, the mass of TCE in the plume down gradient of the study area decreased 11%, reducing the mass of contaminants moving off site.
Primary Contact	Steven Rock, USEPA (513) 569-7149 rock.steven@epa.gov Gregory Harvey, Wright-Patterson AFB (937) 255-7716 gregory.harvey@wpafb.af.mil
Citation	EPA/540/R-03/506

Site Name	Combustion Superfund
Site Location	Denham Springs, LA
Contaminant	1, 2-dichloroethane, polychlorinated biphenyls, benzene, lead, mercury, nickel, silver, toluenediisocyante, toluene diamine
Vegetation Type	Eucalyptus, Poplar, Native Willows
Planting Descriptions	Potted Stock
Media Type	Groundwater
Site Characterizations	5-10' depth of impact
Evapotranspiration Rates	
Climate	Temp. Range: -8 to 102; Elev.: 59 ft; Mean annual precip.: 60.8"; Growing season: 3/18-11/4
Mechanism	Hydraulic control, rhizodegradation, phytovolatilization
Operation/Maintenance Requirements	Mowing
Project Scale	Full-Scale
Project Status	Planted 2002
Cost	Est. Present Worth: Capital Cost = $1,700k, O&M Cost = $561k, Total Cost = $2,261k Est. Present Worth: Site Long-Term Care O&M Cost = $123k Est. Present Worth Pond Area GW Monitoring: Capital Cost = $13k, O&M Cost = $69k, Total Cost = $82k TOTAL: Present Worth Capital Cost = $1,713k, Present Worth O&M Cost = $753k, Present Worth Total Cost = $2,466k
Funding source	Combustion Superfund
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	In-situ hot spot treatment plus phytoremediation and monitored natural attenuation. 5-10 ft (depth of impact)
Primary Contact	Katrina Coltrain, US EPA (214) 665-8143 Todd Thibodeaux, LDEQ (225) 219-3225 David Tsao, BP Remediation Mngmt Function (630) 836-7169 tsaodt@bp.com
Citation	LDEQ, EPA6

Site Name	Contaminated Paint Factory
Site Location	Czech Republic
Contaminant	Polychlorinated Biphenyls
Vegetation Type	Ash, Austrian pines, Black locust and Willow trees
Planting Descriptions	4-24 year old pre-established trees (no planting)
Media Type	Soil
Site Characterizations	
Evapotranspiration Rates	
Climate	
Mechanism	Rhizodegradation
Operation/Maintenance Requirements	None
Project Scale	Field Demonstration
Project Status	
Cost	
Funding source	
Initial concentrations	
Final Concentrations	
Lesson learned	
Comments	Austrian pine and Black locust significantly increased the number of PCB-degrading bacteria in their rhizospheres.
Primary Contact	
Citation	Leigh, M.B., J. Fletcher, D.P. Nagle, P. Prouzova, M. Mackova and T. Macek (2003) Rhizoremediation of PCBS: Mechanistic and Field Investigations

Site Name	Edward Sears Property
Site Location	New Gretna, NJ
Contaminant	PCE, TCE, DCM
Vegetation Type	Hybrid Poplars
Planting Descriptions	118 trees 9'bgs. Deep rooted 10' bare root cuttings. Holes were drilled and plant installed, and backfilled with sand peat mix. 100 trees planted shallow 3'bgs. Hole drilled to top of clay 4-5 feet below grade.
Media Type	Groundwater, Soil: Sand 0-5' bgs sand/silt/clay 5-18' bgs. Equal parts sand silt clay. Below 18' sands and gravel.
Site Characterizations	GW 7-11' bgs
Evapotranspiration Rates	
Climate	Temp. Range: -2 to 102; Elevation: 52 ft; Mean annual precip: 36.7"; Growing season: 5/15-9/28
Mechanism	Phytodegradation Hydraulic control
Operation/Maintenance Requirements	Fertilization, control of deer, insects & unwanted vegetation. NPK and lime added annually.
Project Scale	Field demonstration/full scale, 1 acre
Project Status	Operational/In Progress. 12/1996-on-going. Data as of 1999
Cost	$105,000
Funding Source	USAF, DoD, SITE
Initial concentrations	PCE(1): 160ppb, PCE(2): 100ppb; TCE(1): 390ppb, TCE(2): 9ppb, TCE(3): 99ppb; DCM (1): 490,000ppb, DCM(2): 12,000ppb, DCM(3): 680ppb, DCM(4): 420ppb
Final Concentrations	As of 1999: PCE(2): 56ppb; TCE(1): 390ppb, TCE(2): 35ppb, TCE(3): 42ppb; DCM(1): 615ppb; DCM(2): ND, DCM(3): ND, DCM(4):1.2
Lessons Learned	
Comments	Contamination in sand/silt/clay unit, Most plants survived, DCM concentrations substantially reduced in GW also reductions in TCE after 6 years of treatment
Primary Contact	George R. Prince, USEPA (732) 321-6649 prince.george@epamail.epa.gov
Citation	NATO/CCMS Pilot Study 1998 Annual Report Number 228 EPA/542/R-98/002 Evaluation of Demonstrated and Emerging Technologies for the Treatment of Contaminated Land and Groundwater (Phase III)

Site Name	Eka Chemicals Site
Site Location	Gothenburg, Sweden
Contaminant	
Vegetation Type	PCDFs, chlor-alkalis
Planting Descriptions	
Media Type	
Site Characterizations	
Evapotranspiration Rates	
Climate	
Mechanism	
Operation/Maintenance Requirements	
Project Scale	
Project Status	
Cost	
Funding Source	MISTRA – COLDREM Programme
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Maria Greger, Stockholm University: maria.greger@botan.su.se
Citation	

Site Name	Ellsworth Air Force Base, South Dakota
Site Location	SD
Contaminant	TCE, cis-1,2-DCE
Vegetation Type	Hybrid Poplars (NM 6, DN 17, and DN 182)
Planting Descriptions	1,027 trees
Media Type	
Site Characterizations	GW 5-30' bgs
Evapotranspiration Rates	
Climate	Temp. Range: -23 to 109; Elev.: 3427 ft; Mean annual precip.: 18.6"; Growing season: 5/26-9/14
Mechanism	Hydraulic control
Operation/Maintenance Requirements	
Project Scale	1 acre Demonstration
Project Status	Planted 6/2001
Cost	
Funding Source	
Initial concentrations	TCE (240 ug/l), cis-1,2-DCE (100 ug/l)
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Rafael Vazquez, AFCEE (210) 536-1431 rafael.vazquez@brooks.af.mil
Citation	

Site Name	ERP Site 17, Beale Air Force Base
Site Location	Marysville, CA
Contaminant	TCE, DCM
Vegetation Type	Native Cottonwood (*P. fremontii*), Live Oak (*Quercus wislizenii*), deer grass (*Muhlenbergia rigens*), meadow barley (*Hordeum brachyantherum*), clustered field sedge (*Carex praegracilis*) and narrow-leaved willow (*Salix exigua*)
Planting Descriptions	
Media Type	Groundwater
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp Range: 18-115; Elevation: 69 ft; Mean annual precip: 17.5"; Growing season: 3/23-11/14
Mechanism	Hydraulic control
Operation/Maintenance Requirements	Irrigation
Project Scale	5 acres
Project Status	Planted in 2000
Cost	
Funding Source	
Initial concentrations	TCE, DCM
Final Concentrations	
Lessons Learned	
Comments	Groundwater levels inside the slurry wall need to be maintained at 12 to 14 feet below land surface. (depth of impact). Although the primary purpose of the vegetation is to provide "phyto pumping", is anticipated that VOC mass removal will also occur as a result of transpiration through the plants.
Primary Contact	Michael O'Brien, Beale AFB (530) 634-3856 Michael.O'Brien@beale.af.mil Martin Barackman, CH2M HILL (530) 229-3401 mbarackm@CH2M.com
Citation	Jordahl, J., R. Tossell, M. Barackman and G. Vogt (2003) Phytoremediation for Hydraulic Control and Remediation: Beale Air Force Base and Koppel Stockton Terminal. *Abstracts from US EPA International Applied Phytotechnologies Workshop* March 3-5, 2003 Chicago, IL

Site Name	Fairchild Air Force Base, Washington
Site Location	WA
Contaminant	TCE, DCM
Vegetation Type	Hybrid Poplar (*P. trichocarpa x P. deltoides, P. trichocarpa x P. nigra, P. deltoides x maximoxiczii*)
Planting Descriptions	1,134 cuttings
Media Type	
Site Characterizations	GW 9-11' bgs
Evapotranspiration Rates	
Climate	Temp Range: -25 to 108; Elevation: 1922 ft; Mean annual precip: 16.5"; Growing season: 5/20-9/19
Mechanism	Hydraulic control
Operation/Maintenance Requirements	
Project Scale	1 acre Demonstration
Project Status	planted 4/2001
Cost	
Funding Source	
Initial concentrations	TCE, DCM
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Rafael Vazquez, AFCEE (210) 536-1431 rafael.vazquez@brooks.af.mil
Citation	

Site Name	Fort Lewis Army Base
Site Location	Tacoma, WA
Contaminant	trichloroethene and dichloroethene; PAH
Vegetation Type	Hybrid Poplar
Planting Descriptions	
Media Type	Groundwater
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp Range: -8 to 104; Elevation: 36 ft; Mean annual precip: 50.5"; Growing season: 4/20-10/25
Mechanism	Phytoextraction, phytodegradation
Operation/Maintenance Requirements	
Project Scale	Field Demonstration (pilot), 10 acres
Project Status	Proposed
Cost	
Funding Source	
Initial concentrations	TCE - 5 μg/L
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Bob Kievit, US EPA (360) 753-9014 kievit.bob@epa.gov
Citation	

Site Name	Fringe drain area
Site Location	Argonne, IL
Contaminant	Trichloroethylene
Vegetation Type	Hybrid poplar, willow
Planting Descriptions	809 trees; deep-rooted and planted as 10-16 ft tall trees
Media Type	Soil, Groundwater (silty clay)
Site Characterizations	The edge of the zone of influence for groundwater is 22 ft bgs. The physical aquifer is 30 ft bgs
Evapotranspiration Rates	
Climate	Temp range: -27 to 104; Elevation: 658 ft; Mean annual precipitation: 35.8"; Growing season: 4/25-10/22
Mechanism	Phytodegradation, Hydraulic Control
Operation/Maintenance Requirements	None
Project Scale	Full-scale (5 acres)
Project Status	Ongoing (Planted 1999)
Cost	$750,000 for initial planting; $15,000-$20,000/year operation and maintenance costs (includes research costs). These costs include both Fringe Area and the 317/319 (see separate listing) Argonne sites.
Funding Source	Department of Energy
Initial concentrations	TCE: up to 10-15 ppm (average)
Final Concentrations	
Lessons Learned	Uptake of tritium and TCE is obseved in plants, but no clear consensus in soil concentrations because they vary widely across site due to inumerable factors
Comments	Early tree growth was severely limited as a result of early summer planting in 1999 and a cool summer in 2000. In 2001 and 2002, tree growth has substantially improved with poplar trees achieving 4-6 ft of growth per year. Hydraulic effects by the trees on groundwater were measurable in 2001. Measurable uptake of TCE and Tritium from groundwater is not expected to be realized until late in 2002 or 2003, because of the slow early growth of the trees. 20-30 ft. below ground surface (depth of impact)
Primary Contact	Ed Gatliff, Applied Natural Sciences (513) 895-6061 ans@fuse.net
Citation	Quinn, J., Negri, M., Hinchman, R., Moos, L., Wozniak, J., and E. Gatliff. 2001. "Predicting the Effect of Deep-Rooted Hybrid Poplars on the Groundwater Flow System at a Large-Scale Phytoremediation Site". International Journal of Phytoremediation. 3(1): 41-60.

Site Name	Ft Wayne
Site Location	Ft Wayne, IN
Contaminant	TCE, DCE
Vegetation Type	Hybrid Poplar
Planting Descriptions	800 trees
Media Type	
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp Range: -22 to 106; Elevation: 856 ft; Mean annual precip: 34.7; Growing season: 5/15-9/25
Mechanism	
Operation/Maintenance Requirements	
Project Scale	
Project Status	
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Graham Crockford, RMT (734) 971-7080 graham.crockford@rmtinc.com
Citation	

Site Name	Grand Forks Air Force Base – AOC-539
Site Location	Grand Forks, ND
Contaminant	TCE, DCM
Vegetation Type	Eastern Cottonwood (P. deltoides), Carolina Poplar (P. canadensis), Imperial Carolina Poplar (P. deltoides x P. nigra DN-34 (P. canadensis), Russian Olive (Elaeagnus angustifolia)
Planting Descriptions	All bare root material. Trees planted in 18-inch diameter auger borings 18 to 24 inches deep. Selected trees planted in borings 4 feet deep, but all trees planted at normal depth, i.e., same depth as grown in nursery. Tree spacing is 12' between rows, and 6'between trees within the row.
Media Type	Groundwater, soil
Site Characterizations	Soil: sandy loam 0-1'bgs, clay at 4-10'bgs. Depth to groundwater was 4.3-9.4' in 9/2001, and 2.7-5.8' in 9/2003. Estimated hydraulic gradient prior to site installation was 0.017 ft/ft. In the fall of 2003, gradients ranged from 0.0066-0.016 ft/ft. The estimated hydraulic conductivity is 0.371 ft/day.
Evapotranspiration Rates	Projected ET by 2006 - 28.9 inches (per acre)
Climate	Long term average precipitation - 19.16 inches
Mechanism	Hydraulic control, rhizodegradation, phytodegradation, phytovolatilization
Operation/Maintenance Requirements	Mowing, pruning, irrigation, replanting, animal control, insect control
Project Scale	0.7 acre full scale pilot test
Project Status	Planted 2001
Cost	Planning/design/implementation through 1 year monitoring: approximately $320,000
Initial concentrations	Sept 2001: TCE in soil - max. 2.4 mg/kg, TCE in groundwater - 4900 μg/L, TPH, in soil - max. 1300 mg/kg TPH in groundwater - max. 2400 μg/L
Final Concentrations	Sept 2003: TCE in groundwater - 2700 μg/L, TPH in groundwater - max. 1900 μg/L
Funding Source	Air Force - - Federal Government
Lessons Learned	Winter injury can be a significant factor in site establishment at northern latitudes, but extent of damage appears to be less with increasing tree age. Winter injury from jackrabbits can be significant. Some damage to poplars was noted in the first year despite tree guards (plastic protective sleeves around stem). Significant damage to some Russian olive trees was noted in the second winter.
Comments	Groundwater flow patterns are complex, but to date no significant groundwater depression as a result of evapotranspiration of the trees has developed.
Primary Contact	Larry Olderbak, Grand Forks AFB Environmental (701) 747-4183 larry.olderbak@grandforks.af.mil Al Erickson, CH2M Hill (414) 847-0303 Al.Erickson@CH2M.com
Citation	

Site Name	Hill AFB Operable Unit 4
Site Location	30 miles north of Salt Lake City, UT
Contaminant	Dichloroethane, cis-1,2-Dichloroethylene, Perchloroethene, 1,1,1-Trichloroethane, Trichloroethene, chromium, cadmium, manganese, and arsenic
Vegetation Type	Hybrid Poplar
Planting Descriptions	11 ft whips were implanted at depths of 8-10 ft bgs in order to get roots started nearer water table.
Media Type	Groundwater, soil: silty sands to very fine sands
Site Characterizations	GW 6-10' bgs
Evapotranspiration Rates	avg evapotranspiration = 914 mm water
Climate	temp range 3.9-23.8C ; elevation: 4225 ft; avg precipitation=16.2 in; growing season: April - mid October
Mechanism	Phytovolatilization, Hydraulic control
Operation/Maintenance Requirements	Irrigation
Project Scale	Field Demonstration
Project Status	Ongoing
Cost	approx $175K
Funding Source	Air Force Center for Environmental Excellence
Initial concentrations	trichloroethene, 84 to 560 ug/L
Final Concentrations	no notable decrease has been noted
Lessons Learned	Plants may have a greater impact on TCE attenuation at sites with lower rainfall.
Comments	Estimates of TCE phytovolatilization by whole trees range from 2-53 mg/tree-yr. Note that main object of this effort was not to reduce TCE concentration but was to attempt to provide hydraulic control of groundwater to minimize the continued migration of groundwater contaminants.
Primary Contact	Sandra Bourgeois, US EPA (303) 312-6666 bourgeois.sandra@epa.gov Kyle Gorder, Hill AFB (801) 775-2559 Kyle.Gorder@hill.af.mil
Citation	Final Addendum Report No. 1 to the Interim Technical Report for the Demonstration of Phytostabilization of Shallow Contaminated Groundwater using Tree plantings at Hill Air Force Base, UT (July 2003), prepared for the Air Force Center for Environmental Excellence Science and Engineering Division (AFCEE/ERS), Brooks City-Base, TX. Prepared by Parsons.

Site Name	I-5 Spill
Site Location	Central Point, OR
Contaminant	1,1,1-trichloroethane
Vegetation Type	Hybrid Poplar
Planting Descriptions	800 trees planted in neat ranks
Media Type	
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp range: -25 to 100; Elevation: 4099 ft; Mean annual precip: 12.6"; Growing season: 6/28-8/31
Mechanism	
Operation/Maintenance Requirements	
Project Scale	
Project Status	Planted Nay 1997
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Milton P. Gordon, University of WA (206) 543-1769, miltong@u.washington.edu Lee Newman: University of SC, (803)777-4795, Newman2@gwm.sc.edu Stuart Strand, University of WA (206) 543-5350 sstrand@u.washington.edu
Citation	Schmiedeskamp, M. (1997) POLLUTION-PURGING POPLARS *Scientific American* Dec97m Vol. 27, Issue 6

Site Name	Jones Island CDF
Site Location	Milwaukee, WI
Contaminant	Polychlorinated biphenyls (PCB), Polycyclic aromatic hydrocarbons (PAH), diesel range organics (DRO) and metals
Vegetation Type	Established: Reed Canary Grass (*Phalaris arundinacea*), Sandbar Willow (*Salix interior*), Tall Nettle (*Urtica procera*) Tested: clover (*Trifolium* spp.), corn (*Zea mays*), and willow (*Salix* spp.)
Planting Descriptions	Cuttings planted in 2001
Media Type	Soil
Site Characterizations	Brown to black silt
Evapotranspiration Rates	
Climate	Temp range: -26 to 103; Elevation: 672 ft; Mean annual precip: 32.9"; Growing season: 5/20-9/26
Mechanism	Rhizodegradation
Operation/Maintenance Requirements	
Project Scale	Field demonstration
Project Status	Continuous. Planted 2001
Cost	
Funding Source	US Army
Initial concentrations	PCB: 0-4 mg/kg , PAH: 0-120 mg/kg , DRO: 5-1300 mg/kg
Final Concentrations	
Lessons Learned	
Comments	Composting also implemented using woodchips, biosolids and dredged material.
Primary Contact	Steven A. Rock, US EPA (513) 569-7149
Citation	McCutcheon and J.L. Schnoor, eds., Phytoremediation: Transformation and Control of Contaminants: Hoboken, NJ, John Wiley & Sons, Inc.

Site Name	Kauffman & Minteer
Site Location	Jobstown, NJ
Contaminant	*cis* 1,2-dichloroethene; Trichloroethene, Perchloroethene, Dichlorodiphenyltrichloroethane, endosulfan sulfate, ethyl benzene, 2-methylnapthalene, styrene, toluene,
Vegetation Type	Hybrid poplar and black willow (*Salix Nigra*)
Planting Descriptions	(Populus maximowiczii x P. trichocarpa) 265 trees. Initially 8-10' bare root trees were deep planted 6-8' below grade in sonotubes or other root barriers. 1999 plantings were shallow with no root barriers.
Media Type	Groundwater, soil: silty sand
Site Characterizations	GW 5+' bgs
Evapotranspiration Rates	
Climate	Temp range: -4 to 102; Elevation: 190 ft; Mean annual precip: 42"; Growing season: 4/15 to 10/23
Mechanism	Rhizodegradation
Operation/Maintenance Requirements	Replanting
Project Scale	5 acres
Project Status	Planted Spring 1998. Bay wash area planted Spring 1999.
Cost	
Funding Source	EPA ERT, EPA Region 2
Initial concentrations	Groundwater: 15,000µg/L Trichloroethene; 22,000µg/L *cis* 1, 2 dichloroethene. Soil: 230ppm perchloroethene, 3100 ppm trichloroethene, 1600 ppm 1,1,1-trichloroethane, 1100ppm 1,2-dichloroethene
Final Concentrations	lower concentrations
Lessons Learned	Imported backfill had low pH of 4.5. Liming and watering helped.
Comments	Heavy rains and aggressive string trimming resulted in death of 45 trees in 1998
Primary Contact	George R. Prince: USEPA, 732-321-6649, prince.george@epamail.epa.gov
Citation	Compton, H.R. et al. 2003. "Phytoremediation of Dissolved Phase Organic Compounds: Optimal Site Considerations Relative to Field Case Studies". *REMEDIATION,* summer 2003.

Site Name	Lake City Army Ammunition Plant
Site Location	Kansas City, KS
Contaminant	Halogenated Volatiles
Vegetation Type	Hybrid Poplar
Planting Descriptions	
Media Type	Soil: Top 5 feet is sand (fill), clay below sand layer
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp range: -19 to 110; Elevation: 742 ft; Mean annual precip: 36.1"; Growing season: 4/30 to 10/9
Mechanism	Phytostabilization, phytoextraction
Operation/Maintenance Requirements	
Project Scale	20,000 square feet, 200,000 square feet, 40,000 square feet, 7-10 acres
Project Status	Proposal
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Carol Dona, TVA/AEC (816)-426-7340 carol.l.dona@mrk01usace.army.mil
Citation	

Site Name	Metal Plating Facility
Site Location	Findlay, OH
Contaminant	Chromium, cadmium, nickel, zinc, lead, trichloroethylene
Vegetation Type	Hybrid Poplar, Ryegrass; Indian mustard
Planting Descriptions	30 trees, deep rooted and planted when 10-16 ft tall
Media Type	Soil (silt loam)
Site Characterizations	GW 10-15' bgs
Evapotranspiration Rates	
Climate	Temp range: -19 to 104 ; Elevation: 804 ft; Mean annual precip: 34.5"; Growing season: 5/19 to 9/24
Mechanism	Phytoextraction, Hydraulic Control
Operation/Maintenance Requirements	sampling groundwater
Project Scale	Full-Scale (10,000 sq ft)
Project Status	Operational/In Progress. Planted 1997
Cost	voluntary
Funding Source	State
Initial concentrations	TCE: up to 150 mg/L
Final Concentrations	
Lessons Learned	Dramatic drop of, on average, 30 ppm to less than 5 ppm. However, the source area continues to supply site with contaminants.
Comments	SITE Program. Trees have grown at a rate of 4-8 ft/year. Results of the first 3 years indicated significant reduction of TCE concentrations in the aquifer in addition to demonstration of hydraulic effects on groundwater flow
Primary Contact	Michael Blaylock, Edenspace, (703) 961-8700, blaylock@edenspace.com or Edd Gatliff, Applied Natural Sciences, (513) 895-6061 ans@fuse.net
Citation	Phytoremediation of TCE in Groundwater using Populus. http://www.clu-in.org/products/phytotce.htm

Site Name	Montezuma West
Site Location	Medford, OR
Contaminant	1,1,1-trichloroethane
Vegetation Type	Hybrid Poplar
Planting Descriptions	Planted 5/1997
Media Type	Groundwater, soil
Site Characterizations	GW 8m bgs
Evapotranspiration Rates	
Climate	Very hot dry summers. Temp range: -25 to 100; Elevation: 4099 ft; Mean annual precip: 12.6"; Growing season: 6/28 to 8/31
Mechanism	Phytoextraction, phytodegradation
Operation/Maintenance Requirements	Irrigation, weeding, thinning.
Project Scale	Field Demonstration (pilot), 1 acre
Project Status	1997 Operational/In Progress
Cost	~ $120,000
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Tissue analyses indicate that plants are taking up TCA. Fall site preparation is invaluable. Do not wait until spring.
Primary Contact	Lee Newman, U of SC (803)777-4795, Newman2@gwm.sc.edu
Citation	

Site Name	Moonachie
Site Location	Moonachie, NJ
Contaminant	Toluene
Vegetation Type	DN 34, Hybrid Poplar
Planting Descriptions	Planted 5/1997. Six trees were replaced in the spring of 1998.
Media Type	Groundwater; clay soil
Site Characterizations	GW 2-7' bgs; 2-12' to contamination. -1.77E-3 to 2.71E-6 m/m hydraulic gradient; 1.98E-7 to 3.21E-6 m/sec hydraulic conductivity
Evapotranspiration Rates	
Climate	Temp range: -8 to 105; Elevation: 7 ft; Mean annual precip: 43.9"; Growing season: 4/15 to 10/26
Mechanism	Phytovolatilization, rhizodegradation.
Operation/Maintenance Requirements	Mowing, replanting, monitoring: insect/animal damage, wells
Project Scale	Field Demonstration (pilot)
Project Status	Operational/In Progress (1996-1998)
Cost	$51,005
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Approximately 10% mortality due to transplanting and/or phytotoxicity effects were observed. Project will continue to be monitored. Trees need to be planted earlier in the spring to reduce transplanting shock.
Primary Contact	Ari M. Ferro, Phytokinetics (435) 750-0985 ariferro@phytokinetics.com
Citation	No

Site Name	NASA Kennedy Space Center Hydrocarbon Burn Facility
Site Location	Merritt Island, Cape Canaveral, FL
Contaminant	Dichloroethene, Trichloroethene, Vinyl Chloride, Chromium, TPH
Vegetation Type	Hybrid poplar trees, under story grasses
Planting Descriptions	4400 trees and under story grasses
Media Type	Groundwater, Soil: Medium-coarse sand
Site Characterizations	GW 1-12' bgs
Evapotranspiration Rates	950L/m2-yr
Climate	Semi-tropical. Temp range: 25 to 96 ; Elevation: 9 ft; Mean annual precip: 127cm; Growing season: 2/7 to 12/22
Mechanism	Hydraulic control, phytovolatilization, rhizodegradation, phytoextraction
Operation/Maintenance Requirements	Mowing, irrigation
Project Scale	Full-Scale, 3 acres
Project Status	Active. Planted 4/1998
Cost	$70,000 for Ecolotree portion
Funding Source	
Initial concentrations	0.5 ± 0.09-65 ± 26mg/L trichloroethene; <1.1-1200µg/L 1,1-dichloroethene; 65-4800 µg/L cis-1,2 dichloroethene, <1.65-110µg/L trans-1,2 dichloroethene; <2-456 µg/L vinyl chloride, Chromium > 50 ppb ; TPH = 110-760 ppm
Final Concentrations	
Lessons Learned	Not able to establish phytoplantation due to competing vegetation (grasses) and drought.
Comments	Organic chemical spill site, 1-12 ft. (depth of impact)
Primary Contact	Louis A. Licht: Ecolotree, (319) 665-3547 lou-licht@ecolotree.com Eric Aitchison, Ecolotree (319) 665-3547 eric-aitchison@ecolotree.com
Citation	Phytoremediation. Ed. McCutcheon, S.C., Schnoor, J.L. 2003

Site Name	Naval Undersea Warfare Station
Site Location	Keyport, WA
Contaminant	1,1,1 Trichloroethane, halogenated volatiles
Vegetation Type	Hybrid Poplar
Planting Descriptions	900 cuttings
Media Type	Groundwater
Site Characterizations	GW 15-20' bgs
Evapotranspiration Rates	
Climate	Temp range: 9 to 96; Elevation: 125 ft; Mean annual precip: 37.1"; Growing season: 4/20 to 10/27
Mechanism	Phytoextraction, phytodegradation
Operation/Maintenance Requirements	
Project Scale	Field Demonstration (pilot), 8 acres
Project Status	Operational/In Progress Started 4/2001 to 2009
Cost	
Funding Source	Superfund
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Shallow groundwater elevation data shows no significant effect from the phytoremediation plantation. No significant effect on VOC concentrations is expected until the trees mature.
Primary Contact	Lee Newman: University of South Carolina, (803)777-4795, Newman2@gwm.sc.edu
Citation	Rohrer, W., Newman, L., and B. Wallis. 2000. "Monitoring Site Constraints at NUWC Keyport's Hybrid Poplar Phytoremediation Plantation". In: G. Wickramanayake, A. Gavaskar, B. Alleman, and V. Magar (eds.) Bioremediation and Phytoremediation of Chlorinated and Recalcitrant Compounds, p467-476. Battelle Press, Columbus, Ohio.

Site Name	Northern Iowa Chlorinated Solvent Plume
Site Location	Northern IA
Contaminant	Dichloroethene, perchloroethene, trichloroethene
Vegetation Type	Hybrid poplar trees, under story grasses
Planting Descriptions	700 trees trenched 10' below ground. 15' tall trees to bottom of trench.
Media Type	Groundwater, silty clay loam
Site Characterizations	GW 9-11' bgs
Evapotranspiration Rates	
Climate	Temp range: -30 to 104; Elevation: 1174 ft; Mean annual precip: 34"; Growing season: 5/20 to 9/16
Mechanism	Hydraulic control, rhizodegradation, phytoextraction
Operation/Maintenance Requirements	Mowing, weeding
Project Scale	Full-Scale, 1 acre
Project Status	Active. Planted April 2002
Cost	$100,000 1st year
Funding Source	PRP/Site owner
Initial concentrations	Perchloroethene(up to 15mg/L); trichloroethene(up to 50mg/L)
Final Concentrations	Greater than 30% reduction of TCE
Lessons Learned	
Comments	Tree survival > 95% in year one.
Primary Contact	Roland Newton, GSI, 505-270-6542 Eric Aitchison, Ecolotree (319) 665-3547 eric-aitchison@ecolotree.com
Citation	

Site Name	Oregon Poplar
Site Location	Clackamas, OR
Contaminant	1,1-dichloroethane; 1,1-dichloroethene; 1,2-dichloroethene; perchloroethene, trichloroethene, vinyl chloride, benzene, toluene, ethyl benzene, xylene
Vegetation Type	Native and hybrid poplars
Planting Descriptions	Not planted in rows to facilitate future use of site as park. Planted 12-18" dormant hardwood cuttings or live stakes. More than 900 trees planted.
Media Type	Groundwater
Site Characterizations	GW 2-10' bgs. Silty clay to 10' bgs. Below silty clay is 15-20' poorly sorted gravel-to-cobble.
Evapotranspiration Rates	Some of the larger trees show uptake as much as 25 gal of groundwater per day during the summer.
Climate	Temp range: 6 to 107; Elevation:33 ft; Mean annual precip: 36.3"; Growing season: 4/26 to 10/18
Mechanism	Phytodegradation, phytovolatilization
Operation/Maintenance Requirements	
Project Scale	
Project Status	Planted 1997
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	Additional wells may need to be installed to further define the plume.
Comments	Contaminants found in tissue and transpiration gases indicating trees are utilizing contaminated groundwater and/or soil. Pore water sampling in a nearby stream with passive diffusion bags indicates VOCs are present below State criteria for surface waters.
Primary Contact	Alan M. Humphrey, US EPA (732) 321-6748 humphrey.alan@epa.gov
Citation	Compton, H.R. et al. 2003. "Phytoremediation of Dissolved Phase Organic Compounds: Optimal Site Considerations Relative to Field Case Studies". *REMEDIATION,* summer 2003.

Site Name	Portsmouth Gaseous Diffusion Plant – X-740 TCE Plume
Site Location	Piketon, OH
Contaminant	Trichloroethene (TCE), Perchloroethene (PCE), Dichloroethene (DCE), Vinyl Chloride (VC)
Vegetation Type	Hybrid Poplars(NE-19, DN-34, NM-6)
Planting Descriptions	765 trees planted with "trench and sand-stack" method to a depth of 10'
Media Type	Groundwater, Soil
Site Characterizations	GW 32' bgs, semi contained aquifer
Evapotranspiration Rates	
Climate	Temp range: -19 to 101; Elevation: 833 ft; Mean annual precip: 38.1"; Growing season: 5/9 to 10/3
Mechanism	Hydraulic Control, phytoremediation
Operation/Maintenance Requirements	Mowing and tree care mostly
Project Scale	2.6 acre Full-scale pilot project
Project Status	3/1999
Cost	$500,000
Funding Source	US Dept of Energy
Initial concentrations	TCE: up to about 4,000 ppb
Final Concentrations	TCE: 2-2200μg/L
Lessons Learned	Learned from X-740 Area that we needed to dig the trenches deeper for X-749 Area
Comments	GW levels show direct impact, analytical results less profound. Both phytoremediation areas are relatively young, so concentrations have not changed much yet.
Primary Contact	David E Rieske, Pro2Serve Technical Solutions, (740) 897-2550, riesked@p2s.com
Citation	Brewer, R.D. and D.E. Rieske (2003) TCE Plume Phytoremediation at the Portsmouth Gaseous Diffusion Plant. *Abstracts from US EPA Intn'l Applied Phytotechnologies Workshop* March 3-5, 2003 Chicago, IL Rieske, D.E., et al (2003) Removal of Chlorinated Solvents by Phytoremediation Using Trench and "Sand-Pipe" *Abstracts from US EPA Intn'l Applied Phytotechnologies Workshop* March 3-5, 2003 Chicago, IL

Site Name	Portsmouth Gaseous Diffusion Plant – X-749/X-120 TCE Plume
Site Location	Piketon, OH
Contaminant	Trichloroethene (TCE), Perchloroethene (PCE), Dichloroethene (DCE), Vinyl Chloride (VC)
Vegetation Type	Hybrid Poplars (*Populus Nigra x Populus maximowiczi* (NM-6))
Planting Descriptions	3,450 trees planted in 12-15' deep trenches with 8" sand-stacks every 20'.
Media Type	Groundwater
Site Characterizations	GW 32' bgs, semi contained aquifer. Soil: Unconsolidated alluvial sand and gravel, lacustrian silts and clays
Evapotranspiration Rates	
Climate	Temp range: -19 to 101; Elevation: 833 ft; Mean annual precip: 38.1"; Growing season: 5/9 to 10/3
Mechanism	Hydraulic Control, phytoremediation
Operation/Maintenance Requirements	Mowing and tree care mostly
Project Scale	41 acre full scale Large-scale remediation project
Project Status	Planted spring 2003
Cost	
Funding Source	U.S. Department of Energy
Initial concentrations	TCE: 2-2200µg/L
Final Concentrations	TCE: up to about 500 ppb
Lessons Learned	
Comments	This project is due to results of demo at same site in 1999. Both phytoremediation areas are relatively young, so concentrations have not changed much yet.
Primary Contact	David E Rieske, Pro2Serve Technical Solutions, (740) 897-2550, riesked@p2s.com Roger Brewer, Tetra Tech, Inc. brewer@ttnus.com
Citation	Brewer, R.D. and D.E. Rieske (2003) TCE Plume Phytoremediation at the Portsmouth Gaseous Diffusion Plant. *Abstracts from US EPA Intn'l Applied Phytotechnologies Workshop* March 3-5, 2003 Chicago, IL Rieske, D.E., et al (2003) Removal of Chlorinated Solvents by Phytoremediation Using Trench and "Sand-Pipe" *Abstracts from US EPA Intn'l Applied Phytotechnologies Workshop* March 3-5, 2003 Chicago, IL

Site Name	Sangamo Electric Dump/ Crab Orchard National Wildlife Refuge (USD01)
Site Location	Marion, IL
Contaminant	explosives, polychlorinated biphenyls, trichloroethene and other chlorinated solvents-lead, cadmium, chromium, arsenic
Vegetation Type	Hybrid poplar trees
Planting Descriptions	
Media Type	Groundwater
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp range: -12 to 104; Elevation: 314; Mean annual precip: 46.9"; Growing season: 4/6 to 10/29
Mechanism	
Operation/Maintenance Requirements	
Project Scale	Planned. Planned installation 2004
Project Status	
Cost	
Funding Source	PRP Lead/ Federal Oversight
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Nanjunda Gowda, US EPA (312) 353.9236 gowda.nanjunda@epa.gov
Citation	

Site Name	Savannah River, North Carolina
Site Location	Savannah River, NC
Contaminant	DCE, PCE, VC
Vegetation Type	Hybrid Poplars, loblolly pines
Planting Descriptions	
Media Type	
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp range:-7 to 95; Elevation: 2239 ft; Mean annual precip: 38.8"; Growing season: 4/24 to 10/11
Mechanism	Hydraulic Control
Operation/Maintenance Requirements	
Project Scale	Two one-acre plots
Project Status	Planted ~ 3/2002
Cost	
Funding Source	
Initial concentrations	DCE, PCE, VC
Final Concentrations	
Lessons Learned	
Comments	April 2002 tissue sampling results do not indicate the presence of TCE
Primary Contact	Cassandra Bayer: Bechtel Savannah River, Inc.
Citation	

Site Name	Savannah River Site
Site Location	Aiken, SC
Contaminant	Perchloroethene (PCE), trans-1,2-dichloroethylene, trichloroethene (TCE), trichloromethane
Vegetation Type	Grass, legume, herb, Loblolly Pine, hybrid poplar
Planting Descriptions	
Media Type	Groundwater, Soil: Mostly Udorthents firm substratum with low permeability (basin resulted from removal of much of developed surface soil)
Site Characterizations	Confined to upper 10m of vadose zone. 67.5% sand, 9.0% silt and 23.5% clay.
Evapotranspiration Rates	
Climate	Abundant rainfall. Warm, humid conditions prevail. Temp range: -1 to 108; Elevation: 134 ft; Mean annual precip: 44.6"; Growing season: 4/15 to 10/23
Mechanism	Phytodegradation, rhizodegradation, hydraulic control
Operation/Maintenance Requirements	Irrigation
Project Scale	4 acre-Pilot Scale
Project Status	Operations began 10/2001, scheduled for 3 years.
Cost	
Funding Source	
Initial concentrations	TCE: 900-1400ppb, PCE: <200ppb
Final Concentrations	
Lessons Learned	
Comments	Groundwater irrigated over plants.
Primary Contact	Dawn Taylor, US EPA (404) 562-8575 taylor.dawn@epa.gov
Citation	Walton, B.T and Anderson, T.A. 1990. "Microbial Degradation of Trichloroethylene in the Rhizosphere: Potential Application to Biological Remediation of Waste Sites". Applied and Environmental Microbiology, Apr 1990, p. 1012-1016. Kim, RH et. Al. (2003) Remediation of VOC-Contaminated Groundwater at the Savannah River Site by Phyto-Irrigation. *Abstracts from US EPA International Applied Phytotechnologies Workshop* March 3-5, 2003 Chicago, IL

Site Name	SRSNE (Solvent Recovery Service New England)
Site Location	Southington, CT
Contaminant	Trichloroethane, Dichloroethane, 1,1-Dichloroethylene, Vinyl Chloride, Polychlorinated biphenols
Vegetation Type	Hybrid Poplar (DN 34), white willow, pin oak, river birch, sweet gum, silver maple, tulip tree, eastern red bud, eastern white pine
Planting Descriptions	~1000 hybrid poplars. 3' trenches backfilled w/sand & peat moss.
Media Type	Groundwater, Soil
Site Characterizations	GW 3' bgs; contamination 3' to bedrock 30' bgs.
Evapotranspiration Rates	Water use rates for 2001 averaged 7.8 gpd per tree for willows and 8.4 gpd per Poplar.
Climate	Temp range: -26 to 102; Elevation: 174 ft; Mean annual precip: 44.1"; Growing season: 5/12 to 9/23
Mechanism	Phytovolatilization, rhizodegradation, hydraulic control
Operation/Maintenance Requirements	Mowing, fertilization, replanting, monitoring insect/animal damage
Project Scale	0.8 acre Field Demonstration (pilot)
Project Status	Operational/In Progress. Planted 5/1998. Completion of project planned 2030.
Cost	Estimate $500,000/year
Funding Source	PRP Group-lead, SRSNE Superfund Site-Oversight
Initial concentrations	Trichloroethane 0.1-35mg/kg, Dichloroethane 0.1-25mg/kg
Final Concentrations	
Lessons Learned	Trees need to be planted earlier in the spring to reduce transplanting shock.
Comments	10% mortality due to transplanting and/or phytotoxicity effects were observed. Manual labor for installation was intense.
Primary Contact	Karen Lumino , US EPA (617) 918-1348 lumino.karen@epa.gov
Citation	Ferro, A., Chard, B., Gefell, M., Thompson, B., and R. Kjelgren. 2000. "Phytoremediation of Organic Solvents in Groundwater: Pilot Study at a Superfund Site". In: G. Wickramanayake, A. Gavaskar, B. Alleman, and V. Magar (eds.) Bioremediation and Phytoremediation of Chlorinated and Recalcitrant Compounds, p461-466. Battelle Press, Columbus, Ohio.; Ferro, A., Kennedy, J., Kjelgren, R., Rieder, J., and S. Perrin. 1999. "Toxicity Assessment of Volatile Organic Compounds in Poplar Trees". International Journal of Phytoremediation. 1(1): 9-17.

Site Name	Tibbetts Road
Site Location	Barrington, NH
Contaminant	Trichloroethylene, polychlorinated biphenols. Arsenic, benzene, toluene
Vegetation Type	Hybrid poplar trees (Deltoides x Nigra), under story grasses
Planting Descriptions	1,400 one-year-old rooted plants
Media Type	Groundwater, soil
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp range: -33 to 102; Elevation: 338 ft; Mean annual precip: 36.4"; Growing season: 6/9 to 9/8
Mechanism	Hydraulic control, phytoextraction, rhizosphere
Operation/Maintenance Requirements	Mowing, weeding
Project Scale	Full-Scale, 2 acres
Project Status	Operational. Planted 1998. Estimate completion 2015.
Cost	$40,000 for Ecolotree portion of project. Entire remedy (including source removal, demolition, water supply extension, controls and monitoring) estimated at $8M
Funding Source	Superfund
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Trees have grown well and now stand over 15' tall. Tree survival in 1998 was 99%.
Primary Contact	Neil Handler, USEPA (617) 918-1334 handler.neil@epa.gov
Citation	http://yosemite.epa.gov Waste Site Cleanup & Reuse in New England-TIBBETTS ROAD ITRC (2004) White Paper Case Study. Making the Case for Ecological Enhancements. ECO-1. January 2004

Site Name	Travis Air Force Base
Site Location	CA
Contaminant	Trichloroethene
Vegetation Type	Red ironbark (*Eucalyptus sideroxylon* 'Rosea')
Planting Descriptions	480 trees
Media Type	Groundwater
Site Characterizations	GW 5-8m bgs
Evapotranspiration Rates	2003 Potential ET: Jan-Apr: 45mm, May-Oct, negligible, Nov: 25mm, Dec:125mm
Climate	Temp range: 18 to 115; Elevation: 69 ft; Mean annual precip: 17.5"; Growing season: 3/23 to 11/14
Mechanism	Hydraulic control
Operation/Maintenance Requirements	Irrigation
Project Scale	2.5 acre Demonstration
Project Status	Planted 11/1998
Cost	
Funding Source	AFCEE/ERS
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	No evidence of hydraulic control thru 5th season. Roots found in well near water table. No irrigation applied since 2002. Site will continue to be monitored.
Primary Contact	Rafael Vazquez, AFCEE (210) 536-1431 rafael.vazquez@brooks.af.mil John Lucey, US EPA (415) 972-3243 lucey.john@epa.gov
Citation	"Phytostabilization Demonstration at Travis Air Force Base, California" poster

Site Name	Union Carbide Corporation
Site Location	Texas City, TX
Contaminant	1,2 DCA, BCEE
Vegetation Type	Poplar and Mulberry
Planting Descriptions	40 trees planted
Media Type	Groundwater, soil: sands, silty sands
Site Characterizations	GW 30-35' bgs, K=5E-6cm/s
Evapotranspiration Rates	
Climate	Temp range: 7 to 107; Elevation: 102 ft; Mean annual precip: 47"; Growing season: 3/17 to 11/14
Mechanism	Hydraulic Control
Operation/Maintenance Requirements	Fertilization, irrigation, replanting, pruning, mulching
Project Scale	Full Scale
Project Status	Operational/In Progress
Cost	$20,000
Funding Source	PRP
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Supplement to traditional pump/treat
Primary Contact	Richard J. Chapin, Union Carbide Corp (DOW Chemical) chapinrj@dow.com
Citation	Basel Al-Yousfi A. et al. (2000). "Phytoremediation-The Natural Pump-and-Treat and Hydraulic Barrier System." Practice Periodicals of Hazardous, Toxic, and Radioactive Waste Management, April 2000, p 73-77.

Site Name	Unspecified
Site Location	SC
Contaminant	DCE, PCE, VC
Vegetation Type	Hybrid Poplar and willow
Planting Descriptions	
Media Type	Groundwater
Site Characterizations	
Evapotranspiration Rates	
Climate	
Mechanism	Hydraulic Control, phytoremediation
Operation/Maintenance Requirements	
Project Scale	
Project Status	
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	David McMillan, Natresco (717) 583-2100 dmcmillan@natresco.com
Citation	

Site Name	Unspecified chemical manufacturing facility
Site Location	Aurora, IL
Contaminant	TCE (up to 25 mg/L)
Vegetation Type	Hybrid poplar, willow
Planting Descriptions	200 poplars, 50 willows
Media Type	
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp range: -27 to 104; Elevation: 658 ft; Mean annual precip: 35.8"; Growing season: 4/25 to 10/22
Mechanism	Phytodegradation, Hydraulic Control
Operation/Maintenance Requirements	
Project Scale	
Project Status	planted 2000
Cost	
Funding Source	
Initial concentrations	TCE (up to 25 mg/L)
Final Concentrations	
Lessons Learned	
Comments	Trees have grown consistently (up to 8 ft/year for the Poplar). Comparison of groundwater concentrations from pre-installation of the TreeMediation system and 2 growing seasons later indicate significant reduction of the TCE concentrations in the aquifer both at the source area and on the property boundary. Hydraulic effects on the groundwater flow have also been demonstrated. 10-15 ft below surface (depth of impact)
Primary Contact	Ed Gatliff, Applied Natural Sciences (513) 942-6061 ans@fuse.net
Citation	

Site Name	Vandenberg Air Force Base, California
Site Location	CA
Contaminant	DCE, PCE, VC
Vegetation Type	Hybrid poplar (*P. trichocarpa x P. deltoides, P. trichocarpa x P. nigra, P. deltoides x maximoxiczii*)
Planting Descriptions	1,260 cuttings
Media Type	
Site Characterizations	G' 5-10' bgs
Evapotranspiration Rates	
Climate	Temp range: 20 to 109; Elevation: 16 ft; Mean annual precip: 16.2"; Growing season: 2/26 to 12/4
Mechanism	Hydraulic control
Operation/Maintenance Requirements	
Project Scale	1 acre
Project Status	Planted 8/2001
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Rafael Vazquez, AFCEE (210) 536-1431 rafael.vazquez@brooks.af.mil
Citation	

Site Name	Wayne County
Site Location	Wayne County, MI
Contaminant	DCE, PCE, VC
Vegetation Type	Hybrid Poplar
Planting Descriptions	60 trees deep rooted and planted when 10-16 ft tall.
Media Type	Groundwater, Soil
Site Characterizations	Groundwater 8-10 ft bgs
Evapotranspiration Rates	
Climate	Temperature Range: -13 to 103 F; Mean Annual precipitation: 26.6"; Elevation: 619 ft; Average growing season: 5/12-10/9
Mechanism	Phytodegradation
Operation/Maintenance Requirements	Pruning, monitoring
Project Scale	Full-Scale
Project Status	Inactive (1997-2002)
Cost	30,000
Funding Source	Private
Initial Concentrations	TCE: 600 ppb
Final Concentrations	TCE: 30 ppb
Lessons Learned	Although the site had early successes, by 2002 street salt leaching into groundwater was killing trees. Salinity is too high to support vegetation and there are no trees, and no phytoremediation taking place at site now.
Comments	TCE substantially reduced, 8 ft below ground surface (depth of impact)
Primary Contact	Ed Gatliff, Applied Natural Sciences (513) 895-6061 ans@fuse.net
Citation	http://www.treemediation.com

Site Name	Weyerhaeuser - Timber Processing Site
Site Location	Klamath Falls, OR
Contaminant	Polychlorinated biphenols, Pentachlorophenol, chromate
Vegetation Type	Hybrid poplar trees, under story grasses
Planting Descriptions	
Media Type	Soil: Sandy-loess soil
Site Characterizations	GW 2' bgs
Evapotranspiration Rates	
Climate	Temp range: -25 to 100; Elevation: 4099 ft; Mean annual precip: 12.6"; Growing season: 6/28 to 8/31
Mechanism	Phytoextraction, Rhizodegradation, Phytovolatilization
Operation/Maintenance Requirements	Mowing
Project Scale	Full-Scale, 7 acres
Project Status	Inactive. Planted 1994,1995
Cost	
Funding source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Industrial wastewater containing PCP and PCB is irrigated onto 10 acres of hybrid poplars, thus reducing point-source discharge to receiving streams. Approximately 5% tree loss in year 1 attributed to shallow concrete foundations inhibiting root development.
Primary Contact	Jeannine Brown, US EPA (206) 553-1058 brown.jeannine@epa.gov, Eric Aitchison, Ecolotree (319) 665-3547 eric-aitchison@ecolotree.com
Citation	

Site Name	Wisconsin
Site Location	central WI
Contaminant	TCE
Vegetation Type	Hybrid Polar
Planting Descriptions	300 trees
Media Type	Groundwater, Soil: Loamy sand
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp range: -36 to 99; Elevation: 1191 ft; Mean annual precip: 33"; Growing season: 5/22 to 9/6
Mechanism	
Operation/Maintenance Requirements	
Project Scale	
Project Status	Planted Spring 2004
Cost	$40,000 1st year
Funding source	Federal Facility
Initial concentrations	less than 1mg/L
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Louis A. Licht: Ecolotree, (319) 665-3547 lou-licht@ecolotree.com Eric Aitchison, Ecolotree (319) 665-3547 eric-aitchison@ecolotree.com
Citation	

Appendix B: Pesticides Database

Table of Contents

Site Name	Aberdeen Pesticide Dumps
Site Location	Aberdeen, NC
Contaminants	Dieldrin, hexachlorobenzene, hexachlorahexane
Vegetation Type	Hybrid Poplar trees and groundcover grasses
Planting Descriptions	Depth of planting: 1.5-12 ft.
Media Type	Groundwater (soil: sand and silty clay)
Site Characterizations	Groundwater: Avg. gradient = 0.008 ft/ft; Hydraulic conductivity: 3.82e-4 to 2.03e-3 cm/sec; avg velocity: 343 ft/yr
ET Rates	4 million gallons in 1999 growing season
Climate	Elevation: 339 ft; Mean annual precip: 50.3"; Growing season: 4/23 to 10/13
Mechanism	Hydraulic control, Rhizodegradation
OM Requirements	Mowing, fertilizing, amendments(?), contact Mann
Project Scale	Full scale (7.5 acres, 3500 trees)
Project Status	Ongoing (began 1999)
Cost	$450,000
Funding Source	PRP
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	87,000 tons of soil removed for thermal treatment prior to plant installation
Primary Contact	Luis. E Flores, USEPA, (404) 562-8807, flores.luis@epa.gov or Tom Mann, 864-609-9111
Citation	EPA Superfund: Record of Decision, 1999 and Annual Repot, March 2004

Site Name	Amana #1 & #2
Site Location	Amana, IA
Contaminants	Atrazine, alachlor
Vegetation Type	Corn, Fescue, Hybrid Poplar, Sunflowers (Heianthus annus)
Planting Descriptions	
Media Type	Groundwater, Soil
Site Characterizations	
ET Rates	
Climate	Temp range: -28 to 104 F; Elevation: 902 ft; Mean annual precipitation: 33.4"; Growing season: 5/13 to 9/25
Mechanism	Phytoextraction, phytotransformation
OM Requirements	
Project Scale	Demonstration/Pilot (1 mile x 25 feet)
Project Status	Completed
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Designed as a riparian buffer zone with Ecolotree buffer. Reduction of 10-20% of applied atrazine
Primary Contact	Jerry Schnoor, University of Iowa, (319) 335-5585, jschnoor@engineering.uiowa.edu
Citation	Schnoor, J. L., L.A. Licht, S.C. McCutcheon, N.L. Wolf, and L.H. Carreira. 1995. Phytoremediation of organic and nutrient contaminants. Environmental Science & Technology, 29(7): 318A-323A.

Site Name	Bofors-Nobel Superfund Site
Site Location	Muskegon, MI
Contaminant	3,3 Dichlorobenzidine, vinyl chloride, Perchloroethene, Aniline, Azobenzene, Benzidine, 3,3 Dichlorobenzidine, Toluene
Vegetation Type	hybrid poplar
Planting Descriptions	
Media Type	Groundwater, soil
Site Characterizations	GW 6' bgs
Evapotranspiration Rates	
Climate	Temp. Range: -15 to 99 F; Elev.: 644; Mean annual precip.: 32.6"; Growing season: 5/24-9/24
Mechanism	Rhizodegradation, phytoextraction, phytodegradation
Operation/Maintenance Requirements	cutting down any tree species that does not survive in the contained area
Project Scale	Pilot scale. Approximately 20 acres of planted tree species, with another (approx.) 20 acres of engineered treatment wetlands.
Project Status	On hold. Planted 6/2004
Cost	Estimated total remedy cost can be from about $ 15 million up to $ 30 million.
Funding source	PRP, Federal/State overview
Initial concentrations	Up to 3000-10000 ppm for halogenated and nonhalogenated semi-volatiles
Final Concentrations	
Lessons Learned	
Comments	Phytoremediation is not the main goal of the remedy. The main goal is containment using the underground barrier (slurry) wall, with phyto as an enhancement.
Primary Contact	John Fagiolo, USEPA (312) 886.0800 fagiolo.john@epa.gov Ari Ferro, Phytokinetics (435) 750-0985 ariferro@phytokinetics.com
Citation	

Site Name	Cantrall
Site Location	Cantrall, IL
Contaminant	Nitrate nitrogen, herbicides/insecticides, atrazine, alachlor
Vegetation Type	Hybrid Poplar
Planting Descriptions	200 poplar trees
Media Type	Groundwater, Soil (Glacial soils; silt; clay)
Site Characterizations	Groundwater varies 4-17 feet bgs seasonally.
ET Rates	
Climate	Temperature Range: -22 to 106 F; Mean Annual Precipitation: 35.3"; Elevation: 617 ft; Growing season: 5/1 to 10/6
Mechanism	Phytodegradation, rhizodegradation, phytostabilization
OM Requirements	Pruning; mowing; drip irrigation of contaminated water.
Project Scale	Full-Scale (2 acres)
Project Status	Operational (planted 1992)
Cost	Planting & irrigation: $300,000; O&M: $0/yr (currently)
Funding Source	Private
Initial concentrations	Nitrate: 150 ppm
Final Concentrations	Nitrate: 50 ppm
Lessons Learned	
Comments	Primarily for the reduction of nitrates and herbicides in groundwater. Soils have not been retested to date. Groundwater collection/ irrigation system installed with trees to serve as recirculating in-situ treatment system.
Primary Contact	Paul Thomas, Thomas Consultants, (513) 271-0092, pt@thomasconsultants.com or Todd Gross, IL State EPA, (217) 524-4862,
Citation	Thomas Consultants, Inc. Project Descriptions document

Site Name	Clarence Coop Martelle Plant
Site Location	Martelle, IA
Contaminant	Atrazine, herbicides, nitrate, ammonia/ammonium
Vegetation Type	Hybrid poplar trees and understory grasses
Planting Descriptions	1100 trees planted
Media Type	Groundwater, Soil (Silty soil underlain by glacial till)
Site Characterizations	
ET Rates	
Climate	Temp Range: -28 to 104 F; Mean Annual Precipitation: 33.4"; Elevation: 902 ft; Growing season: 5/13 to 9/25
Mechanism	Phytostabilization, rhizodegradation, phytoextraction
OM Requirements	Observe insect predation; Mowing, weeding, replanting in areas where ammonia was toxic to trees.
Project Scale	Full-Scale (0.3 acre)
Project Status	Inactive (1993)
Cost	$15,000
Funding Source	Clarence Coop
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Agrochemical spill site (Ecolotree Buffer, EBuffer). Ammonia proved to be toxic to hybrid poplars in some areas. Replanting successfully completed in 1994 by amending soil with compost and adding lime to raise soi pH and convert ammonium to ammonia gas. Many trees over 20' tall after three growing seasons
Primary Contact	Louis A. Licht, Ecolotree, (319) 358-9753, lou-licht@ecolotree.com
Citation	

Site Name	Connecticut Agricultural Experiment Station
Site Location	New Haven, CT
Contaminant	p,p'-dichlorodiphenyldichloethylene (p-p'-DDE), chlordane
Vegetation Type	Cucurbita species
Planting Descriptions	
Media Type	
Site Characterizations	
ET Rates	
Climate	Temperature Range: -26 to 102 F; Mean Annual Precipitation: 44.1"; Elevation: 174 ft; Growing season: 5/12 to 9/23
Mechanism	
OM Requirements	
Project Scale	
Project Status	
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Jason White, (203)-974-8523, Jason.White@po.state.ct.us
Citation	2003 Phytotechnologies Conference Abstract

Site Name	Fort Winwright
Site Location	Fairbanks, AK
Contaminants	Aldrin, DDD, DDT, dieldrin, petroleum hydrocarbons
Vegetation Type	Felt leaf willow dominant
Planting Descriptions	Invasive species (felt leaf willow) took over site\
Media Type	Soil
Site Characterizations	Groundwater varies between 5-15 feet bgs
ET Rates	
Climate	Temperature Range:-62 to 96 F; Mean Annual Precipitation:10.9"; Elevation: 499 ft; Growing season: 5/25 to 8/25
Mechanism	Rhizodegradation, Phytoextraction
OM Requirements	Corn syrup, alcohol amendments, saturated, fertilized, irrigated, fenced
Project Scale	Full scale (850 cubic yards)
Project Status	Completed (1997-2002)
Cost	
Funding Source	US Army
Initial concentrations	
Final Concentrations	
Lessons Learned	Aldrin concentrations decreased; dieldrin concentrations did not. After treatment, soils from site were deposited in Fort Wainwright landfill rather than an offsite hazardous waste landfill.
Comments	Soil excavated and relocated into lined treatment cells for phytoremediation.
Primary Contact	Diane Soderland, EPA, (907)271-3425, soderlund.dianne@epa.gov
Citation	First Five Year Review Report for Fort Wainwright, Alaska; Sept. 2001

Site Name	Illinois Fertilizer/Herbicide Spill Site
Site Location	IL
Contaminants	Nitrogen, herbicides
Vegetation Type	Hybrid poplar trees and understory grasses
Planting Descriptions	440 trees planted
Media Type	Soil and groundwater
Site Characterizations	Groundwater at 4-6' bgs
ET Rates	
Climate	
Mechanism	Hydraulic control, phytoextraction, rhizodegradation
OM Requirements	Mowing, weeding, fertilization
Project Scale	Full-scale
Project Status	Active (began 4/1999)
Cost	
Funding Source	Facility owner
Initial concentrations	Nitrate/nitrite = 20-200 mg/L; alachlor = 0.1-3 mg/L
Final Concentrations	
Lessons Learned	
Comments	Agrochemical spill site. The trees grew 15 feet in the 17 months following planting, and appear to have taken up a significant volume of groundwater. Only 6,000 gallons of groundwater were obtained from an on-site recovery well in 2000, compared to 16-23,000 gallons per year for
Primary Contact	Louis A. Licht, Ecolotree, (319) 358-9753, lou-licht@ecolotree.com
Citation	

Site Name	Iowa State University microplot
Site Location	Ames, IA
Contaminant	Atrazine, metolachlor, pendimethalin, trifluran
Vegetation Type	big blue stern, indian yellow grass, switchgrass, and mixtures of grasses
Planting Descriptions	from pots, inoculated with pesticides prior to transplantation into soil
Media Type	Soil (loamy soil, 1.6% organic matter)
Site Characterizations	Microplots were 24x30x18 cm deep
ET Rates	
Climate	Temperature Range: F; Mean Annual Precipitation: "; Elevation: ft; Growing season:
Mechanism	
OM Requirements	Fortified soil (pesticides added)
Project Scale	Field microplot
Project Status	4 year study
Cost	
Funding Source	Partial funding from Center for Health Efects of Environmental Contaminants at University of Iowa
Initial concentrations	Atrazine: 25 mg/kg; metolachlor: 35 mg/kg; trifluran: 25 mg/g; pendimethalin: 110 mg/g
Final Concentrations	Atrazine: 10 mg/kg
Lessons Learned	
Comments	No significant difference between vegetated and non-vegetated microplots for atrazine and metolachlor, despite increased dissipation into prarie grasses. Pendimethalin and trifluran were more persistent. No vegetation differences for pendimenthalin but for trifluran concentrations were significantly lower in vegetated plots
Primary Contact	Joel Coats, IA State Univ, (515) 294-4776, jcoats@iastate.edu or Todd A. Anderson, Texas Tech University, (806) 885-4567, todd.anderson@ttu.edu
Citation	Final Report: EPA Grant Number r825549c045. Available at http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/5250/report/F Belden, JB; Clark, BW; Phillips, TZ; Hendersen, KL; Arthur, EL; Coats, JR. 2003. Detoxification of Pesticide Residues in Soil Using Phytoremediation. *ACS Symposium Series 863: Pesticide Decontamination and Detoxification*, Chapter 12. Ed: JJ Gan, PC Zhu, SD Aust, AT Lemley. American Chemical Society, 2003.

Site Name	Lockwood Farm
Site Location	Hamden, CT
Contaminants	p-p'-DDE (p,p'-dichlorodiphenyldichloehtylene)
Vegetation Type	21 cultivar varieties of Cucurbita pepo
Planting Descriptions	Planted from seedlings
Media Type	Soil (fine sandy loam)
Site Characterizations	
ET Rates	
Climate	Temperature Range: -26 to 102 F; Mean Annual Precipitation: 44.1"; Elevation: 174 ft; Growing season: 5/12 to 9/23
Mechanism	
OM Requirements	Weeding, irrigation, harvesting
Project Scale	Demonstration/ Pilot
Project Status	Completed (destroyed Aug 2002)
Cost	
Funding Source	
Initial concentrations	p-p-DDE: 200-1200 ng/g (dry weight)
Final Concentrations	
Lessons Learned	
Comments	Certain cultivars of C. pepo are better able to phytoextract highy weathered POP's than others, likely due to variations in exudate quantity and composition across cultivars.
Primary Contact	Jason White, (203)-974-8523, Jason.White@po.state.ct.us
Citation	White, JC; Wang, X; Gent, MPN; Iannucci-Berger, W; Eitzer, BD; Schultes, NP; Arienzo, M; Mattina, MI. 2003. Subspecies Level Variation in the Phytoextraction of Weathered p,p'-DDE by Cucurbita pepo. *Environmental Science and Technology*. 37(2003): 4368-4373.

Site Name	McCormick and Baxter Superfund Site
Site Location	Portland, OR
Contaminant	Pentachlorophenol (PCP); fluoroanthene; pyrene; chrysene; Benzo(k)fluoroanthene, polyaromatic hydrocarbons
Vegetation Type	Hybrid Poplar, ryegrass
Planting Descriptions	
Media Type	Soil (surface soil is sand)
Site Characterizations	
ET Rates	
Climate	Temperature Range: 6 to 107 F; Mean Annual Precipitation: 36.3"; Elevation: 33 ft; Growing season: 4/26 to 10/18. Additional details: 65C average summer temperature; 40C average winter temperature; 60 percent average relative humidity in mid-afternoon; 60 percent possible sunshine in summer; 14 km/hr average maximum windspeed.
Mechanism	Rhizdegradation; Phytodegradation
OM Requirements	Irrigation; Fertilization
Project Scale	Full scale (225 sq meters)
Project Status	Completed (3/97-?)
Cost	U.S. EPA SITE Emerging Technology Program Award ($300,000). Budget includes both greenhouse and field-scale studies for years 1996 and 1997.
Funding Source	
Initial concentrations	PCP = 80.4 +/- 23.4 mg/kg; fluoroanthene = 21.8 +/- 6.1 mg/kg; pyrene = 33.5 +/-10.7 mg/kg; chrysene = 11.3 +/-2.6 mg/kg; Benzo(k)fluoroanthene = 4.2 +/- 1.0 mg/kg
Final Concentrations	
Lessons Learned	Variability in soil contaminant concentrations may obscure treatment effects. Variability can be reduced by normalizing data for soil moisture and correcting soil contaminant concentrations by comparison with a recalcitrant soil contaminant. Pre-mixing
Comments	
Primary Contact	Ari M. Ferro, Phytokinetics, (801) 750-0950, ariferro@phytokinetics.com
Citation	

Site Name	Mid-Lakes Farm Service Cooperative
Site Location	Bonduel, WI
Contaminant	Pesticides, herbicides, volatile organic compounds (VOCs)
Vegetation Type	Grass, Hybrid Poplar
Planting Descriptions	
Media Type	Soil, groundwater (sandy soil)
Site Characterizations	10' of sandy soil underlain by peat and sandstone bedrock. Groundwater is 4-7 below ground surface
ET Rates	
Climate	Temperature Range: -29 to 99 F; Mean Annual Precipitation: 28.8"; Elevation: 699 ft; Growing season: 5/26 to 9/18
Mechanism	Hydraulic control, phytoextraction, rhizodegradation, soil stabilization, rhizofiltration
OM Requirements	Mowing, weeding, insect control
Project Scale	Full-Scale (0.3 acres)
Project Status	Operational (began May 1996)
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Hybrid poplars planted as an Ecolotree-cap on 1 acre. Results are pending.
Primary Contact	Louis A. Licht, Ecolotree, (319) 358-9753, lou-licht@ecolotree.com
Citation	

Site Name	Oconee, IL
Site Location	Oconee, IL
Contaminant	alachlor, atrazine, metoachlor, metribuzin
Vegetation Type	Hybrid poplar
Planting Descriptions	Planted from cuttings
Media Type	Groundwater, soil (silt loam)
Site Characterizations	Groundwater located between 4-10 ft bgs
ET Rates	
Climate	Temperature range: -22 to 106 F; Mean annual precipitation: 39.4"; Elevation: 535 ft; Average growing season: 5/1 to 10/6
Mechanism	Rhizosphere degradation
OM Requirements	irrigation to use groundwater, treatment
Project Scale	Full-scale (1.5 acres)
Project Status	Ongoing (began 1988)
Cost	$30000 (Including $10,000/acre planting)
Funding Source	Private
Initial concentrations	Alachlor: 750 ppb groundwater, 150 ppm soil; Atrazine: 1200 ppb groundwater, 850 ppm soil; Metoachlor: 1000 ppb groundwater, 50 ppm soil; Metribuzin: 300 ppb groundwater
Final Concentrations	Alachlor: 100 ppb groundwater (1996), <10 ppm soil (1990); atrazine: 60 ppb groundwater (1996), <10 ppm soil (1990); Metoachlor: 1000 ppb groundwater (1996), <10 ppm soil (1990); Metribuzin: < 10 ppb groundwater (1996)
Lessons Learned	Periods of continuous data logging and monitoring
Comments	Concentration data is approximate, estimated from graphic
Primary Contact	Edd Gatliff, Applied Natural Sciences, Inc., (513) 942-6061, ans@fuse.net or Paul Thomas, Thomas Consultants, (513) 271-0092, pt@thomasconsultants.com
Citation	http://www.treemediation.com/

Site Name	Former Orchard Site
Site Location	Picatinny Arsenal, New Jersey
Contaminant	Arsenic (from arsenical pesticides)
Vegetation Type	Brake Fern
Planting Descriptions	Transplanted from pots
Media Type	Soil (loam soil)
Site Characterizations	Groundwater >20 feet below ground surface
ET Rates	
Climate	Temperature Range: -4 to 102 F; Elevation: 171 ft; Mean annual precipitation: 45.9"; Growing season: 4/15-10/26
Mechanism	Phytoextraction
OM Requirements	Irrigation, lime amendments, and fertilizer
Project Scale	Demonstration plots (10,000 sq ft)
Project Status	Ongoing (2001)
Cost	
Funding Source	US Army
Initial concentrations	As: 10 ppm to 60-70 ppm
Final Concentrations	
Lessons Learned	
Comments	Original turf grass was removed. A greenhouse was constructed on site for overwintering ferns
Primary Contact	Michael Blaylock, Edenspace, (703) 961-8700, blaylock@edenspace.com
Citation	

Site Name	Union Pacific Railroad
Site Location	Laramie, WY
Contaminant	pentachlorophenol, polyaromatic hydrocarbons
Vegetation Type	Cottonwood, willow, hackberry bushes, alfala, dryland grass mixture
Planting Descriptions	
Media Type	Soil
Site Characterizations	
ET Rates	
Climate	Temperature Range: -50 to 94 F; Mean Annual Precipitation: 10.6"; Elevation: 7186 ft; Growing season: 6/26 to 8/26
Mechanism	
OM Requirements	Nutrient amendments added
Project Scale	Full-scale (140 acres)
Project Status	Ongoing
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Other treatments used at site: 2 mile slurry wall, dual-drain liner system, nutrient amendments
Primary Contact	Felix Flechas, EPA, 303-312-6014, flechas.felix@epa.gov
Citation	US EPA REACHIT: http://www.epareachit.org/

Site Name	Weyerhauser - Timber Processing Site
Site Location	Klamath Falls, OR
Contaminant	Halogenated semi-volatiles (PCP, PCB) and metals (chromate)
Vegetation Type	Hybrid poplar trees and understory grasses
Planting Descriptions	
Media Type	Soil (Sandy-loess soil)
Site Characterizations	GW 2' bgs
ET Rates	
Climate	Temperature Range: -25 to 100 F; Mean Annual Precipitation: 12.6 "; Elevation: 4099 ft; Growing season: 6/28 to 8/31
Mechanism	Phytoextraction, Rhizodegradation, Phytovolatilization
OM Requirements	Mowing
Project Scale	Full-Scale (7 acres, 10 acres)
Project Status	Operational
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Industrial wastewater containing PCP and PCB is irrigated onto 10 acres of hybrid poplars, thus reducing point-source discharge to receiving streams. Approximately 5% tree loss in year 1 attributed to shallow concrete foundations inhibiting root development.
Primary Contact	Louis A. Licht, Ecolotree, (319) 358-9753, lou-licht@ecolotree.com
Citation	

Site Name	Whitewater
Site Location	Whitewater, WI
Contaminant	Nitrate Nitrogen, herbicides/insecticides, silvex
Vegetation Type	Grass, Hybrid Poplar, Legumes
Planting Descriptions	Trees were deep rooted and planted when 10-16 ft tall.
Media Type	Groundwater, Soil
Site Characterizations	Site is situated on a porous aquifer medium of fractured bedrock. Groundwater is 5 to 10 feet bgs.
ET Rates	
Climate	Temperature Range: -30 to 104 F; Mean Annual precipitation: 30.9"; Elevation: 872 ft; Average growing season: 5/13-9/25
Mechanism	Hydraulic control
OM Requirements	None, aside from brief monitoring in early stages of project
Project Scale	Full-Scale (10 acres)
Project Status	Operational (began 1990)
Cost	$30,000
Funding Source	private
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Industrial wastewater containing PCP and PCB is irrigated onto 10 acres of hybrid poplars, thus reducing point-source discharge to receiving streams. Approximately 5% tree loss in year 1 attributed to shallow concrete foundations inhibiting root development. Overall reductions in concentrations observed.
Primary Contact	Ed Gatliff, Applied Natural Sciences, Inc., (513) 942-6061, ans@fuse.net
Citation	

Site Name	Former farm market
Site Location	WI
Contaminant	Pesticides, nitrates, ammonium
Vegetation Type	Hybrid poplars
Planting Descriptions	
Media Type	Soil, groundwater
Site Characterizations	
ET Rates	
Climate	
Mechanism	
OM Requirements	
Project Scale	
Project Status	Ongoing (began Spring 1992)
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Louis A. Licht, Ecolotree, (319) 358-9753, lou-licht@ecolotree.com
Citation	

Site Name	Wilmington
Site Location	Wilmington, NC
Contaminant	Nitrate nitrogen, pesticides, ammonium
Vegetation Type	Hybrid Poplar
Planting Descriptions	Trees were deep rooted and planted when 10-16 ft tall. Nutrients added prior to planting
Media Type	Groundwater, Soil (sandy, coastal soil)
Site Characterizations	Groundwater is 10-15 ft bgs
ET Rates	
Climate	Temperature range: 0 to 102 F; Mean annual precipitation: 54.2"; Elevation: 52 ft; Average growing season: 4/11 to 11/3
Mechanism	Hydraulic control
OM Requirements	None
Project Scale	Full-Scale (6 acres)
Project Status	Operational (1992- 2002)
Cost	$30,000
Funding Source	Private
Initial concentrations	
Final Concentrations	
Lessons Learned	Reduction of contaminants was observed at first, but then a site on the property boundary became a continuous source of contamination
Comments	Nitrogen levels in downgradient wells have steadily fallen.
Primary Contact	Edd Gatliff, Applied Natural Sciences, Inc., (513) 942-6061, ans@fuse.net
Citation	

Appendix C: Explosives Database

Table of Contents

TNT = trinitrotoluene
RDX = 1,3,5-trinitro-1,3,5-triazine
HMX = 1,3,5,7-tetranitro-1,3,5,7-tetraazocyclooctane
DNT = dinitrotoluene
PC = perchlorate
AN = Ammonium Nitrate
2NT = 2-nitrotoluene
4NT = 4-nitrotoluene

Site Name	ICI Explosives Americas Engineering
Site Location	Joplin, MO
Contaminant	Ammonium nitrate; Dinitrotoluene
Vegetation Type	Bald Cypress, Hybrid Poplar, Ninebark, Willow
Planting Descriptions	18,000 trees in various arrangements, rooted and bare-root cuttings
Media Type	Groundwater, Soil (in situ), Surface Water
Site Characterizations	Surface water and small drainages; wetlands systems; shallow groundwater; soils and sediments and sandy silts.
Evapotranspiration Rates	
Climate	Temp. Range: -15 to 108 F; Elev: 987 ft; Mean annual precip.: 43.2"; Growing season: 4/25-10/22
Mechanism	Rhizodegradation, phytoextraction
Operation/Maintenance Requirements	Irrigation, weeding
Project Scale	Field Demonstration. 3.2 acres
Project Status	Active remedial. Planted 2/1996
Cost	$40, 000-installation, $20,000-oversight and planning.
Funding Source	The cost of management was born by the client.
Initial concentrations	Ammonium nitrate = 20-1,000 mg/kg soil; Dinitrotoluene = 0.8-200 ug/L water.
Final Concentrations	
Lessons Learned	Management (weeding, watering of upland plants) is essential for a good rate of plant establishment. Effective design and installation is futile unless there is a solid management program later in the growing season and during subsequent years.
Comments	Many trees died, especially trees planted on upland areas, because of extremely poor management following planting.
Primary Contact	Ari M. Ferro, Phytokinetics (435) 750-0950 ariferro@phytokinetics.com
Citation	

Site Name	Iowa AAP
Site Location	Middletown, IA
Contaminant	RDX (hexahydro 1,3,5-trinitro-1,3,5triazine) and TNT (2,4,6-trinitro-toluene)
Vegetation Type	hybrid poplar tree Populus Deltoides X Nigra DN34
Planting Descriptions	700 Hybrid Poplar Trees per acre, planted as 8 ft "whips".
Media Type	Soil
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp Range: -23 to 101 F; Elevation:533 ft ; Mean annual precip:34.5"; Growing season: 5/3 to 10/5
Mechanism	
Operation/Maintenance Requirements	
Project Scale	Full Scale Constructed Wetlands
Project Status	
Cost	
Funding Source	CERCLA
Initial concentrations	RDX: 800ppb
Final Concentrations	RDX: <0.25ppb
Lessons Learned	RDX disappearance in gw slower than TNT. Wetlands estimated to remove approx 0.016-0.019 mg/L TNT and 0.133-0.291 mg/L-day RDX at 25ºC @steady state. Plant growth reduced, but still considerable. Toxic ranges of TNT and RDX were estimated to be 5 to 7 mg/L (in hydroponic culture).
Comments	acute toxicity assays (<14 d) showed poplar had a significant tolerance to explosives concentrations of 5 mg/L
Primary Contact	Jerry Schnoor, University of Iowa (319) 335-5649 jschnoor@engineering.uiowa.edu Kevin Howa, Omaha Corps of Engineers kevin.m.howe@usace.army.mil
Citation	Kiker, J.H., S. Larson, D.D. Moses, and R. Sellers. Use of Engineered Wetlands to Phytoremediate Explosives Contaminated Surface Water at the Iowa Army Ammunition Plant, Middletown, Iowa.

Site Name	Joliet Army Ammunition Plant
Site Location	Joliet, IL
Contaminant	trinitrotoluene (TNT), Tetryl, cyclotrimethylenetrinitramine (RDX)
Vegetation Type	Hybrid poplars (*Populus* spp.) or willows (*Salix* spp.) or native prairie grasses
Planting Descriptions	slurry reactor
Media Type	Groundwater
Site Characterizations	Shallow aquifer
Evapotranspiration Rates	
Climate	Temp. Range: -27 to 104 F; Elev: 658 ft; Mean annual precip.: 35.8"; Growing season: 4/25 to 10/22
Mechanism	Hydraulic Control, phytodegradation
Operation/Maintenance Requirements	
Project Scale	
Project Status	1998, proposal
Cost	$191,000 research grant
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	The site did not use phytoremediation for remediation. Costs estimated at $15M from investigation through remediation including excavation and off-site disposal)
Primary Contact	Jerry Schnoor, University of Iowa (319) 335-5586. GRACE Bioremediation Technologies, Inc. [DARAMEND®] Missauga, Ontario, Canada Bill Rainey, Plexus Scientific brainey@plexsci.com 301-622-9696
Citation	Multiple Biotechnology Demonstrations of Explosives-Contaminated Soils, http://aec.army.mil/prod/usaec/et/restor/ecsoils.htm, 2000.

Site Name	Longhorn Army Ammunition Plant, Burning Ground #3
Site Location	Marshall, Texas
Contaminant	Perchlorate
Vegetation Type	hybrid poplar trees (Populus Deltoides Nigra, DN34)
Planting Descriptions	425 poplar trees were planted
Media Type	Groundwater
Site Characterizations	GW 168-171' bgs. Clayey soils
Evapotranspiration Rates	1,000,000 gal/acre/yr (groundwater is pumped up and drip irrigated onto trees)
Climate	Temp Range: 3 to 107 F; Elevation: 417 ft; Mean annual precipitation: 50"; Growing season: 4/2-10/27
Mechanism	Phytodegradation, Rhizodegradation
Operation/Maintenance Requirements	Complete Environmental Service: Trees inspected & irrigated regularly, amendments, sample collection
Project Scale	0.7 acre Demonstration
Project Status	Planted March 17, 2003, continuing through 2005
Cost	installation and maintenance costs $42,000; research, analysis and monitoring $200,000
Funding Source	Department of the Army, Operations Support Command
Initial concentrations	Perchlorate: ~100 mg/L
Final Concentrations	Perchlorate: 10 mg/L
Lessons Learned	The mass of perchlorate taken up by poplar trees and/or degraded within in the rhizosphere was essentially zero (-0.261 ± 0.016 kg/d). Therefore, between April 2003 and March 2004, no perchlorate was removed from the groundwater by the hybrid poplar trees and/or the microbes that grow in the root zone. However, due to a complicated hydrogeological setting and trenching, it is difficult to obtain a tight water balance and mass balance on perchlorate to prove efficacy of treatment in the field.
Comments	Trees are growing well; phytoremediation system is functioning well. Only 5% of trees have died over the first growing season. Test plot was irrigated with perchlorate contaminated water since the water level was too deep for the roots of the poplar trees to reach. Approximately 116,320 gallons of water was applied to the site between April and November 2003. Irrigation was discontinued for the remainder of the non-growing season on November 17.
Primary Contact	Jerry Schnoor, University of Iowa (319) 335-5649 jschnoor@engineering.uiowa.edu
Citation	Schnoor, J.L., et al. (2004) Demonstration Project of Phytoremediation and Rhizodegradation of Perchlorate in Groundwater at the Longhorn Army Ammunition Plant, The University of Iowa, Dept of Civil and Envi Engr.

Site Name	Milan AAP
Site Location	Milan, Tennessee
Contaminant	trinitrotoluene (TNT), cyclotrimethylenetrinitramine (RDX), and cyclotetramethylenetetranitramine (HMX)
Vegetation Type	Aquatic and wetlands plants. Parrot feather,
Planting Descriptions	Constructed wetland
Media Type	Groundwater, soil
Site Characterizations	Field-scale wetland demonstration
Evapotranspiration Rates	
Climate	Temp. Range: -13 to 105 F; Elevation: 420 ft; Mean annual precip: 55.2"; Growing season: 4/8 to 10/27
Mechanism	Phytodegradation
Operation/Maintenance Requirements	
Project Scale	1/8 acre field demonstration
Project Status	June 1996-Sept 1997
Cost	$1.8M
Funding Source	DoD
Initial concentrations	TNT (1.8mg/l), RDX (2.2mg/l), HMX (0.13 mg/l)
Final Concentrations	Lagoon and gravel-bed wetlands are reducing TNT below 0.002 mg L-l. Lagoon wetland is not as effective with removal efficiencies of only 47 and 20%, respectively.
Lessons Learned	
Comments	Growth of most plants except parrot-feather, was reduced in groundwater containing 1.5 to 3.7 mg TNT L-1
Primary Contact	Darlene Bader-Lohn, US AEC (410) 436-6861 darlene.bader-lohn@aec.apgea.army.mil
Citation	Army Environment Center, Aberdeen Proving Grounds, *report* SFIM-AEC-ET-CR-97059 Sikora, F.L. et al (1997), "Phytoremediation of explosives in groundwater at the Milan Army Ammunition Plant using innovative wetlands-based treatment technologies". *Presentation 15. In 12th Annual Conference on Hazardous Waste Research - Abstracts Book, May 19-22, 1997, Kansas City, MO.* Best, E.P.H. et al (1997), Fate and mass balances of [14C]-TNT and [14C]-RDX in aquatic and wetland plants in groundwater from the Milan Army Ammunition Plant *Presentation 14. In 12th Annual Conference on Hazardous Waste Research - Abstracts Book, May 19-22, 1997, Kansas City, MO.*

Site Name	New Mexico State University
Site Location	Las Cruces, NM
Contaminant	2,4,6-trinitrotoluene (TNT), 1,3,5-trinitro-1,3,5-triazine (RDX), 1,3,5,7-tetranitro-1,3,5,7-tetraazocyclooctane (HMX)
Vegetation Type	Datura innoxia
Planting Descriptions	Cell suspension cultures
Media Type	
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp. Range: -8 to 112 F; Elev: 3908 ft; Mean annual precip: 8.8"; Growing season: 4/14 to 10/28
Mechanism	Phytodegradation
Operation/Maintenance Requirements	
Project Scale	Bench scale
Project Status	Completed 1999
Cost	
Funding Source	
Initial concentrations	TNT (750-1000 ppm)
Final Concentrations	Within 12 h, less than 1% of the initial TNT remained in the growth medium
Lessons Learned	
Comments	Aminodinitrotoluenes (ADNTs), metabolites of TNT, accumulated transiently in cell lysates, and to a lesser extent in cell media. ADNT concentrations started to decrease after 3 h. After 12 h, less than 5% of the initial TNT could be detected as ADNT. Total ADNTs never exceeded 26% of initial TNT, suggesting that additional biotransformation steps also occurred
Primary Contact	
Citation	M. E. LUCERO, W. MUELLER, J. HUBSTENBERGER, G. C. PHILLIPS, and M. A. O'CONNELL, Tolerance to Nitrogenous Explosives and Metabolism of TNT by Cell Suspensions of Datura Innoxia. *Society for In Vitro Biology* (1998)

Site Name	NIKE Missile Site
Site Location	Kent County, MD
Contaminant	Trichloroethene
Vegetation Type	poplar trees
Planting Descriptions	several hundred trees planned
Media Type	
Site Characterizations	
Evapotranspiration Rates	Estimate will pump 50gal/day
Climate	Temp. Range: -7 to 105 F; Elev: 148 ft; Mean annual precip: 40.7 "; Growing season: 4/11 to 10/29
Mechanism	
Operation/Maintenance Requirements	
Project Scale	
Project Status	Proposal
Cost	
Funding Source	
Initial concentrations	>5ppb limit
Final Concentrations	Kent County Forestry Board - seek private funding
Lessons Learned	
Comments	Expects positive results in 4-5 years
Primary Contact	
Citation	DoD (2001) County Considers Phytoremediation Of TCE at Former Nike Missile Site. *Defense Cleanup* Feb. 9, 2001, v12 i9, p 45

Site Name	University of Iowa
Site Location	Iowa City, IA
Contaminant	Trinitrotoluene (TNT), cyclotrimethylenetrinitramine (RDX), 1,3,5,7-tetranitro-1,3,5,7-tetraazocyclooctane (HMX)
Vegetation Type	*Populus Deltoides x Nigra*
Planting Descriptions	greenhouse study
Media Type	Hydroponic Solution
Site Characterizations	
Evapotranspiration Rates	
Climate	Temp. Range: -28 to 104 F; Elev: 902 ft; Mean annual precip.: 33.4"; Growing season: 5/13 to 9/25
Mechanism	Phytodegradation
Operation/Maintenance Requirements	
Project Scale	12 day greenhouse study
Project Status	Completed as of 2003
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	TNT, RDX, and HMX show different fates in poplars. Leachability and toxicity of unknown metabolites should be considered.
Comments	HMX removed more slowly than RDX, and TNT removed faster than nitramine explosives in 12 days.
Primary Contact	
Citation	Yoon, J.M, B. Van Aken, B. Flokstra and J.L. Schnoor (2003) Uptake and Fate of Explosives: TNT, RDX, and HMX in Popular Tissues (Populus Deltoides x Nigra)

Site Name	Volunteer AAP
Site Location	Chattanooga, TN
Contaminant	Trinitrotoluene (TNT), 2,4-Dinitrotoluene (2,4DNT), 2,6-Dinitrotoluene (2,6DNT), 2-nitrotoluene (2NT), and 4-nitrotoluene (4NT)
Vegetation Type	Elodea Canadensis Rich. in Michx. (Elodea) and the emergent Typha angustifolia L. (narrow-leaved cat-tail). July: Ceratophyllum demersum L. (coontail) and Potamogeton nodosus Poir (American pondweed).
Planting Descriptions	Constructed wetland
Media Type	Surface Water
Site Characterizations	Top foot contaminant. Sandy soil
Evapotranspiration Rates	
Climate	Temp. Range: -10 to 105 F; Elev: 689 ft; Mean annual precip: 53.5"; Growing season: 4/18 to 10/19
Mechanism	
Operation/Maintenance Requirements	
Project Scale	Green house scale
Project Status	Completed. 115-day Field demonstration May-September 1996
Cost	Estimated $50,000
Funding Source	U. S. Army Engineer District, Omaha (Missouri River Organization), the U. S. Department of Defense Environmental Security Technology Certification Program (ESTCP), and the Department of Defense Strategic Environmental Research and Development Program (SERDP).
Initial concentrations	2.7 mg/L TNT, 16.7 mg/L 24DNT, 5.2 mg/L 26DNT, 42.6 mg/L 2NT, and 30.5 mg/L 4NT
Final Concentrations	planted sediment reactors in full sunlight removed 22 g TNT, 104 g 24DNT and 38 9 26DNT (592-L system) over the 115-day operational period; the unplanted sediment reactors in full sunlight removed 34 9 TNT,779 24DNT and 62 9 26DNT(1071-L system); and the unplanted sediment reactors in LV-filtered sunlight removed 25 9 TNT, 34 9 24DNT and 26 9 26DNT (1071-L system)
Lessons Learned	Elodea failed to grow in VAAP water, coontail and American pondweed both failed to survive in VAAP water.
Comments	The hydraulic retention time was 7 days.
Primary Contact	Darlene Bader-Lohn, US AEC (410) 436-6861 darlene.bader-lohn@aec.apgea.army.mil
Citation	Miller, J.L., E.P.H. Best, and S.L. Larson (1997), "Degradation of explosives in groundwater at the Volunteer Army Ammunition Plant in flow-through systems planted with aquatic and wetland plants" Presentation 13.12th Annual Conference on Hazardous Waste Research - Abstracts Book, May 19-22, 1997, Kansas City, MO.

Site Name	Wainwright Firing range
Site Location	Alberta, Canada
Contaminant	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), copper, lead, zinc, barium
Vegetation Type	Alfalfa(*Medicago sativa*), bush bean(Phaseolus vulgaris), canola(Brassica rapa), wheat(Triticum aestivum) and perennial rye grass(Lolium perenne)
Planting Descriptions	
Media Type	
Site Characterizations	Sandy Loam: 60% sand, 20% silt by weight
Evapotranspiration Rates	
Climate	Dry prairie climate
Mechanism	Phytoextraction
Operation/Maintenance Requirements	
Project Scale	Greenhouse study with site soil. Analysis of vegetation existing at site.
Project Status	
Cost	
Funding Source	
Initial concentrations	HMX: 32ppm, copper: 790-1000ppm, lead: 85-96ppm, zinc: 100-120ppm, barium: 100-120ppm
Final Concentrations	
Lessons Learned	
Comments	Sampling of indigenous plants at site revealed prairie grass, brome grass, wild bergamot, low bush blueberry, anemone, common thistle, western sage and Drummond's milk vetch to contain extractable HMX, but TNT or RDX.
Primary Contact	
Citation	Groom, C.A, A. Halasz, L. Paquet, N. Morris, L. Olivier, C. Dubois and J. Hawari (2002) Accumulation of HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) in Indigenous and Agricultural Plants Grown in HMX-Contaminated Anti-Tank Firing-Range Soil. *Environ. Sci. & Technol.* 2002, Vol 36, Issue 1 p112-118

Site Name	Weldon Spring Former Army Ordnance Works
Site Location	MO
Contaminant	trinitrotoluene, dinitrotoluene, lead
Vegetation Type	Treatment slurry
Planting Descriptions	
Media Type	Surface water, Soil, Sludge, and Sediment
Site Characterizations	Clayey gravel with sand
Evapotranspiration Rates	
Climate	Temp. Range: F; Elev: ft; Mean annual precip.: "; Growing season:
Mechanism	
Operation/Maintenance Requirements	
Project Scale	Demonstration/Bench scale
Project Status	1993
Cost	Estimated \$147/m^3 with possible additional \$131/m^3 for additional technical assistance, nutrients, carbon source and other process enhancers.
Funding Source	USEPA/SITE
Initial concentrations	TNT: 1500 mg/kg dry weight
Final Concentrations	TNT: 8.7 mg/kg dry weight. TNT reduced by 99.4% over 9 months
Lessons Learned	Treatment time found to be approximately 9 months.
Comments	Treatment slurry
Primary Contact	Tom Lorenz, US EPA (913) 551-7292 lorenz.thomas@epa.gov
Citation	Ex-Situ Anaerobic Bioremediation System: TNT, J. R. Simplot Company EPA 540-R-95-529

Site Name	Werk Tanne
Site Location	Harz, Germany
Contaminant	trinitrotoluene
Vegetation Type	white rot fungi, mycorrhiza; spruce; poplar; elder
Planting Descriptions	Heavy duty soil grader loosened, aerated and homogenized top 30cmof soil. Straw with white rot fungi added followed by layer of bark mulch.
Media Type	Soil
Site Characterizations	Brown soil from loessy loam
Evapotranspiration Rates	
Climate	Cool, humid mountain climate. Altitude: 560m, Precipitation: 1,300mm/a, Avg Annual Temperature: 6.2ºC.
Mechanism	Rhizodegradation
Operation/Maintenance Requirements	
Project Scale	25m X 20m
Project Status	May-99
Cost	
Funding Source	
Initial concentrations	1000mg TNT / mg dm soil
Final Concentrations	Lower TNT concentrations brought to near detection limits within 6 months after grading. Higher TNT concentrations lowered, but not down to detection limit.
Lessons Learned	
Comments	
Primary Contact	Dr. Hartmut Koehler, University of Bremen 49-421-218-4179 a13r@uni-bremen.de
Citation	Koehler, H., J. Warrelmann, T. Frische, P. Behrend, and U. Walter. (2002) In-Situ Phytoremediation of TNT-Contaminated Soil. *Acta Biotechnologia* 22:1-2, 67-80.

Appendix D: Metals Database

Table of Contents

An = Antimony
As = Arsenic
Ba = Barium
Be = Beryllium
Cd = Cadmium
Cr = Chromium
Co = Cobalt
Cs = Cesium
Cu = Copper
Pb = Lead
Ni = Nickel
Ag = Silver
Tl = Thallium
V = Vanadium
Zn = Zinc

Site Name	317/319 Area - Argonne National Laboratory
Site Location	Lemont, IL
Contaminant	Perchloroethene, Trichloroethene, Carbon Tetrachloride, Chloroform, Zinc, Lead, Arsenic, Tritium
Vegetation Type	Eastern gamagrass, Hybrid Poplar, Golden Weeping Willow, Hybrid Prairie Cascade Willow, Laurel-leaved willow
Planting Descriptions	800 whips planted. 420 poplars installed in deep, lined boreholes (TreeWells®) 389 willows and poplars planted at or near surface. Used patented TreeWells® and TreeMediation® (Applied Natural Sciences Inc)
Media Type	Groundwater, Soil: Top-Bottom: 10' silty clay, 2' shallow aquifer, 8" silty clay, 10' silt/sand/silty clay deep aquifer
Site Characterizations	Groundwater 25-30' bgs, aquifer 5'
Evapotranspiration Rates	
Climate	Temp. Range: -27 to 104 F; Elev: 658 ft; Mean annual precip.: 35.8"; Growing season: 4/25-10/22
Mechanism	Phytostabilization, phytoextraction, phytodegradation, rhizodegradation
Operation/Maintenance Requirements	Fertilization, replanting, and significant Health/Safety expenditures because of radiological and other concerns
Project Scale	Full-scale (4 acres)
Project Status	Ongoing (planted 1999)
Cost	$1.2 million
Funding Source	US DOE
Initial Concentrations	n/a; varies considerably throughout site, from ppb to ppm
Final Concentrations	n/a; varies considerably throughout site, from ppb to ppm
Lessons Learned	TreeWells® installed in effort to achieve hydraulic control
Comments	TCE and PCE and breakdown products (trichloroacetic acid) were detected in branch tissue of trees planted in contaminated soil in less than a year. TCE and PCE present in trees down gradient of plume after 2 yrs.
Primary Contact	Cristina Negri, Argonne National Laboratory (630) 252-9662 negri@anl.gov Ed Gatliff, Applied Natural Sciences (513) 895-6061 ans@fuse.net
Citation	Negri, M.C., et al 2003 Root Development and Rooting at Depths, in S.C. McCutcheon and J.L. Schnoor, eds., Phytoremediation: Transformation and Control of Contaminants: Hoboken, NJ, John Wiley & Sons, Inc. p233-262, 912-913 Quinn, J.J., et al 200 Predicting the Effect of Deep-Rooted Hybrid Poplars on the Groundwater Flow System at a Phytoremediation Site: International Journal of Phytoremediation, vol. 3, no. 1, p. 41-60

Site Name	Anaconda Smelter Site, MT
Site Location	Anaconda, MT
Contaminant	Arsenic, cadmium, copper, and zinc
Vegetation Type	Various; over 36 grass, forb, and sub-shrub species and excessions
Planting Descriptions	Planted from seeds, native species was focus although cultivated species were grown to evaluate performance
Media Type	Soil (loam)
Site Characterizations	3-5% grade, sloping north; groundwater depth > 100 ft
ET Rates	
Climate	Temperature range: -52 to 99 F; Elevation: 4467 ft; Mean annual precipitation: 14.7"; Growing season: 6/19-8/31
Mechanism	Phytostabilization; no evidence of phytoextraction
OM Requirements	Fertilization (NPK 12-16-30, applied at rate of 500 lb/acre, 6" depth), amendments (lime kiln dust, applied 22 tons/acre to 12" depth)
Project Scale	Full-scale (1.5 acres)
Project Status	Ongoing (began mid 1990's, EPA work began 2001)
Cost	$350,000 (10 years, total); $200,000 (EPA, since 2001)
Funding Source	EPA, State of Montana Natural Resources Damage Program
Initial concentrations	Cu: range 1020-2180 mg/kg (pre-tillage), pH: 4.00-4.9 (0-6" rooting zone)
Final Concentrations	Cu: average 832 mg/kg, range 525-1080 mg/kg (post-planting)
Lessons Learned	Soil amendments (lime) and fertilizer greatly help to establish vegetation. Native species perform better than commercially available cultivated species.
Comments	Pre-tilling pH was phytotoxic to plants, amendments and fertilization added prior to establishment of vegetation.
Primary Contact	Jay Cornish, MSE Technology, (406) 494-7329, jay.cornish@mse-ta.com
Citation	Development of Acid/ Heavy Metal Tolerant Cultivars (DATC) Project Bi-Annual Report. 2003. Prepared for the EPA Mine Waste Technology Program (Activity III Project 30) and the State of Montana Natural Resource Damage Program (Contract#600121) by Leslie Marty, DATC

Site Name	Anderson
Site Location	Anderson, SC
Contaminant	Lead, cadmium, sulfate, nitrate
Vegetation Type	Grass, Hybrid Poplar
Planting Descriptions	live cuttings, deep-rooted
Media Type	Groundwater, Soil (sandy clay and weathered rock 0-100 feet consisting of mica and saprolite)
Site Characterizations	Groundwater varies 0-18 feet (topographical)
ET Rates	
Climate	Temperature Range: -6 to 103 F; Mean Annual Precip: 50.6"; Elevation: 956 ft; Growing season: 4/15-10/19
Mechanism	Phytostabilization
OM Requirements	Mowing; pruning, replanting
Project Scale	Full-scale (17 acres)
Project Status	Operational (began 1993)
Cost	Maintenance and monitoring costs: $20,000/ yr. Planting costs: $40,000
Funding Source	Private
Initial concentrations	
Final Concentrations	
Lessons Learned	Concentration of metals in surface water has decreased significantly.
Comments	Phytoremediation is combined with passive anoxic limestone drain system to treat groundwater.
Primary Contact	Paul Thomas, Thomas Consultants, (513) 271-0092, pt@thomasconsultants.com
Citation	Personal communication

Site Name	Argonne NL West 1
Site Location	Idaho Falls, ID
Contaminant	Cesium-137
Vegetation Type	Koshia scoparia
Planting Descriptions	hydro-seeded
Media Type	Soil; 40% bondfarm loamy sand, 30% rock outcrop, 20% grassy butte loamy sand
Site Characterizations	Effective rooting depth is 10-20 inches. Available water capacity is low
ET Rates	
Climate	Northern high desert, very low humidity, short growing season, less than 5 days above 100 C, 45 C typical nighttime temperature. Temperature range: -38 to 102 F; Elevation: 4728 ft; Mean annual precipitation: 230 mm; Growing season: 6/14 to 9/4
Mechanism	Phytoextraction
OM Requirements	Irrigation (system with automated sensors based on soil moisture content), Manure addition, non-potasssium fertilizer, pest control (Roundup), harvesting (manual)
Project Scale	Demonstration/ Pilot (1500 cubic yards)
Project Status	Inactive
Cost	2.5 million
Funding Source	Government agency, PRP
Initial concentrations	Cs-137: 30.53 pCi/g
Final Concentrations	Data available Fall '04
Lessons Learned	
Comments	Initial costs could be reduced significantly from this project because of readily available information that currently exists
Primary Contact	Scott Lee, Argonne West, 208-533-7829, scott.lee@anlw.anl.gov
Citation	Various CERCLA documents, including EPA Superfund Record of Decision: Idaho National Engineering Laboratory, OU 21. 9/29/98. EPA/ROD/R10-98/061 1998. (http://www.epa.gov/superfund/sites/rods/fulltext/r1098061.pdf)

Site Name	Argonne NL West 2
Site Location	Idaho Falls, ID
Contaminant	Silver
Vegetation Type	Hybrid willow
Planting Descriptions	hand-planted, spaced 18 inches apart
Media Type	Soil; 40% bondfarm loamy sand, 30% rock outcrop, 20% grassy butte loamy sand
Site Characterizations	Effective rooting depth is 10-20 inches. Available water capacity is low
ET Rates	n/a
Climate	Northern high desert, very low humidity, short growing season, less than 5 days above 100 C, 45 C typical nighttime temperature. Temperature range: -38 to 102 F; Elevation: 4728 ft; Mean annual precipitation: 230 mm; Growing season: 6/14 to 9/4
Mechanism	Phytoextraction
OM Requirements	Irrigation (system with automated sensors based on soil moisture content), Manure addition, non-potasssium fertilizer, pest control (Roundup), harvesting (manual)
Project Scale	Demonstration/ Pilot (500 cubic yards)
Project Status	Inactive
Cost	2.5 million
Funding Source	Government agency, PRP
Initial concentrations	Silver: 352 mg/kg
Final Concentrations	Data available Fall '04
Lessons Learned	
Comments	Initial costs could be reduced significantly from this project because of readily available information that currently exists
Primary Contact	Scott Lee, Argonne West, 208-533-7829, scott.lee@anlw.anl.gov
Citation	Various CERCLA documents, including EPA Superfund Record of Decision: Idaho National Engineering Laboratory, OU 21. 9/29/98. EPA/ROD/R10-98/061 1998. (http://www.epa.gov/superfund/sites/rods/fulltext/r1098061.pdf)

Site Name	Argonne NL West 3
Site Location	Idaho Falls, ID
Contaminant	Mercury
Vegetation Type	Hybrid willow
Planting Descriptions	hand-planted, spaced 18 inches apart
Media Type	Soil; 40% bondfarm loamy sand, 30% rock outcrop, 20% grassy butte loamy sand
Site Characterizations	Effective rooting depth is 10-20 inches. Available water capacity is low
ET Rates	n/a
Climate	Northern high desert, very low humidity, short growing season, less than 5 days above 100 C, 45 C typical nighttime temperature. Temperature range: -38 to 102 F; Elevation: 4728 ft; Mean annual precipitation: 230 mm; Growing season: 6/14 to 9/4
Mechanism	Phytoextraction
OM Requirements	Irrigation (system with automated sensors based on soil moisture content), Manure addition, non-potasssium fertilizer, pest control (Roundup), harvesting (manual)
Project Scale	Demonstration/ Pilot (500 cubic yards)
Project Status	Inactive
Cost	2.5 million
Funding Source	Government agency, PRP
Initial concentrations	Mercury: 3.94 mg/kg
Final Concentrations	Data available Fall '04
Lessons Learned	
Comments	Initial costs could be reduced significantly from this project because of readily available information that currently exists
Primary Contact	Scott Lee, Argonne West, 208-533-7829, scott.lee@anlw.anl.gov
Citation	Various CERCLA documents, including EPA Superfund Record of Decision: Idaho National Engineering Laboratory, OU 21. 9/29/98. EPA/ROD/R10-98/061 1998. (http://www.epa.gov/superfund/sites/rods/fulltext/r1098061.pdf)

Site Name	Argonne NL West 4
Site Location	Idaho Falls, ID
Contaminant	Chromium and mercury
Vegetation Type	Hybrid willow
Planting Descriptions	hand-planted, spaced 18 inches apart
Media Type	Soil; 40% bondfarm loamy sand, 30% rock outcrop, 20% grassy butte loamy sand
Site Characterizations	Effective rooting depth is 10-20 inches. Available water capacity is low
ET Rates	n/a
Climate	Northern high desert, very low humidity, short growing season, less than 5 days above 100 C, 45 C typical nighttime temperature. Temperature range: -38 to 102 F; Elevation: 4728 ft; Mean annual precipitation: 230 mm; Growing season: 6/14 to 9/4
Mechanism	Phytoextraction
OM Requirements	Irrigation (system with automated sensors based on soil moisture content), Manure addition, non-potasssium fertilizer, pest control (Roundup), harvesting (manual)
Project Scale	Demonstration/ Pilot (500 cubic yards)
Project Status	Inactive
Cost	2.5 million
Funding Source	Government agency, PRP
Initial concentrations	Mercury: 3.94 mg/kg; Chromium: 709 mg/kg
Final Concentrations	Data available Fall '04
Lessons Learned	
Comments	Initial costs could be reduced significantly from this project because of readily available information that currently exists
Primary Contact	Scott Lee, Argonne West, 208-533-7829, scott.lee@anlw.anl.gov
Citation	Various CERCLA documents, including EPA Superfund Record of Decision: Idaho National Engineering Laboratory, OU 21. 9/29/98. EPA/ROD/R10-98/061 1998. (http://www.epa.gov/superfund/sites/rods/fulltext/r1098061.pdf)

Site Name	Atlas Tack Corporation Superfund Site
Site Location	Fairhaven, MA
Contaminant	Benzene, Copper, Chromium, cyanide, Mercury, Nickel, Zinc
Vegetation Type	To be determined
Planting Descriptions	
Media Type	Groundwater
Site Characterizations	
ET Rates	
Climate	Temperature Range: -12 to 95 F; Elevation: 15 ft; Mean annual precipitation: 47.9"; Growing season: 4/20-10/22
Mechanism	
OM Requirements	
Project Scale	Full-scale
Project Status	Pre-design
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	Phytoremediation will follow Phase I (demolition) and Phase II (dredging) activities.
Primary Contact	**Elaine Stanley, EPA, 617-918-1332, stanley.elainet@epa.gov**
Citation	Not available: pre-design

Site Name	Austin, TX Residential Site
Site Location	Austin, TX
Contaminant	Arsenic (from CCA)
Vegetation Type	Hyperaccumulating fern (Pteris)
Planting Descriptions	Ferns transplanted from pots
Media Type	Soil (silt loam)
Site Characterizations	
ET Rates	Groundwater > 15 feet bgs
Climate	Temperature Range: 4 to 106 F; Elevation: 617 ft; Mean annual precipitation: 31.9"; Growing season: 3/21 to 11/5
Mechanism	Phytoextraction
OM Requirements	Owner prepared soil, fertilization, 50 kg/hectare N , no P,50 kg/hectare K, irrigatation (hose), harvesteing
Project Scale	Demonstration/Pilot (500 sq ft)
Project Status	Completed (May 2003-Sept 2003)
Cost	$3000-$4000
Funding Source	EPA
Initial concentrations	As: 30-40 ppb
Final Concentrations	As: 20 ppb
Lessons Learned	
Comments	
Primary Contact	Backyard residential site after deck removal; homeowner took intiative. This is completed phase I project; phase II would include an industrial site in FL and 120 residential/ garden/ playground sites.
Citation	Michael Blaylock, Edenspace, (703) 961-8700, blaylock@edenspace.com
Site Name	Phytoextraction of CCA-derived As: EPA SBIR Phase 2 Application

Site Name	Bayonne, NJ
Site Location	Bayonne, NJ
Contaminant	Heavy metals
Vegetation Type	Indian mustard (Brassica juncea)
Planting Descriptions	Planted from seeds
Media Type	Soil (sandy loam)
Site Characterizations	Soil contaminated to 15 cm below ground surface
ET Rates	
Climate	Temperature Range: -8 to 105 F; Elevation: 7 ft; Mean annual precipitation: 43.9"; Growing season: 4/18 to 10/19
Mechanism	Phytoextraction
OM Requirements	Fertilization, harvesting, EDTA and acetic acid amendments
Project Scale	Demonstration/ Pilot (1000 sq ft)
Project Status	Completed (1996)
Cost	
Funding Source	
Initial concentrations	Pb: 1000-6500 (avg. 2,055) mg/kg surface soil; 780-2100 (avg. 1,280) mg/kg subsurface soil (15-30 cm depth); 280-8800 mg/kg (30-45 cm depth)
Final Concentrations	Pb: 420-2300 (avg. 960) mg/kg surface soil; 992 mg/kg (15-30 cm); no change (30-45 cm)
Lessons Learned	Lead concentrations in shoots attained 0.4%. Decrease of total site area with concentration exceeding 1000 mg/kg, from 73% to 32%. No leaching of lead nor EDTA observed as a result of EDTA addition.
Comments	
Primary Contact	Michael Blaylock, Phytotech (now Edenspace), (703) 961-8700, blaylock@edenspace.com
Citation	http://www.edenspace.com

Site Name	Big River Mine Tailings
Site Location	Desloge, MO
Contaminant	Cadmium, lead, zinc
Vegetation Type	tall fescue (Festuca aerundinacea Schreb., cv.Kentucky 31)
Planting Descriptions	40 plots (4 rows, each row with one of three amendments or control, with 10 plots per row); seeded
Media Type	Soil (fine-grained tailings from froth/chemical flotation process for concentrating metals in milled ore)
Site Characterizations	Initial bulk density of tailings material ranged between 1.52 to 1.66 grams per cubic centimeter (average 1.59 g/cm3)
ET Rates	
Climate	Temperature range: -18 to 107 F; Mean low temperature: 43 F; Mean high temperature: 65 F; Elevation: 564 ft; Mean annual precipitation: 3.6"; Growing season: 4/30 to 1/8
Mechanism	Phytoextraction
OM Requirements	Fertilization, weeding, irrigation, harvesting, addition of three organic soil amendments (milorganite, ormiorganics compost, St. Peters compost)
Project Scale	Demonstration/ pilot (7704 square feet)
Project Status	Completed (2000-2002), but monitoring may be extended
Cost	Demonstration cost: $17,200 per acre; full scale estimate: $5000-$15,000 per acre (variation due to cost of compost)
Funding Source	US EPA Mine Waste Technology Program
Initial concentrations	
Final Concentrations	
Lessons Learned	The overall evidence indicates that the Ormiorganics high application rate and St. Peters Compost high application rate treatments are most promising for reclaiming the BRMTS. However, a more vigorous comparison of the respective treatments should be performed before committing to use either amendment for full-scale reclamation of the BRMTS. Therefore, larger scale testing of these two treatments should be performed.
Comments	
Primary Contact	Darcy Byrne-Kelly, MSE Technology, (406) 494-7419, dbyrne@mse-ta.com
Citation	MSE Technology Applications, Inc., *Interim Report for the Revegetation of Mining Waste Using Organic Amendments and the Potential for Creating Attractive Nuisances for Wildlife Demonstration Project*, MWTP-189, July 2001 and Final Report MWTP-239, March 2004

Site Name	Bunker Hill
Site Location	Couer d' Alene, ID
Contaminant	Lead, Zinc
Vegetation Type	Mix of herbaceous species: Western wheat grass
Planting Descriptions	
Media Type	Soil
Site Characterizations	Steep slopes, some greater than 100%
ET Rates	
Climate	Temperature Range:-25 to 108 F; Elevation: 1922 ft; Mean annual precipitation: 16.5"; Growing season: 5/20 to 9/19
Mechanism	Phytostabilization
OM Requirements	
Project Scale	Full-scale (1,050 acres)
Project Status	Completed (1998-2001)
Cost	
Funding Source	
Initial concentrations	Zn: 6000-14700 mg/kg; Pb: 2100-27,000 mg/kg; Cd: 9-28 mg/kg
Final Concentrations	
Lessons Learned	
Comments	Biosolids (56 and 112 Mg/ha) combined with wood ash (157 Mg/ha) and log yard waste
Primary Contact	Rufus Chaney, USDA, (301) 504-8324, chaneyr@ba.ars.usda.gov
Citation	Brown, S.L. and R.L. Chaney. 2000. Combining residuals to achieve specific soil amendment objectives. pp. 343-360. *In* J. Bartels (ed.) Land Application of Agricultural, Industrial and Municipal By-Products. Soil Science Society of America, Madison, WI.

Site Name	Cooperative Farm
Site Location	Bytom, Poland
Contaminant	Cadmium, lead, zinc
Vegetation Type	Brassica sp, Sinapis alba, Helianthus sp, Ricinus communis, Zea mays
Planting Descriptions	Herbicide applied, weeds removed, plowing, and fertilization prior to planting. Seeding followed Phytotech, Inc. recommendations on depth, density, seeds/hole.
Media Type	Soil (Sandy clay)
Site Characterizations	Depth to groundwater > 11 ft. Site topography ranges from moderately flat to significant sloping (2-20% slope)
ET Rates	
Climate	
Mechanism	Phytoextraction
OM Requirements	Fertilization (N, S, P, K), irrigation, chelation (EDTA amendment), harvesting, weed control
Project Scale	Full-scale (0.5 ha)
Project Status	Ongoing (planted Spring `97)
Cost	US $11 per square meter
Funding Source	
Initial concentrations	Pb: 391.4-11.96 mg/kg soil; Cd: 637.5-11.96 mg/kg
Final Concentrations	
Lessons Learned	The most efficient plant species in phytoextraction of lead in field experiments was indian mustard (Brassica juncea) provided by Phytotech. Brachinia (Brassica ol-eracea var. capitata x Brassica napus), provided by IETU, was less effective in com-parison with indian mustard. However Brachinia is less susceptible to environmental conditions compared to indian mustard and can grow well on variety of soil types. The highest concentrations of lead and cadmium in plants shoots was observed 2 weeks after treatment II (IETU) application. This treatment was especially effective for mature form of indian mustard.
Comments	Harvested materials were deposited in hazardous waste dumps.Weather (temperature, rainfall, wind speed, direction, humidity, light, deposition), soil chemistry, and plant monitoring occurred at site.
Primary Contact	Rafal Kucharski, Institute from Ecology of Industrial Areas, +48 32 254 00 29, sas@ietu.katowice.pl
Citation	Institute for Ecology of Industrial Areas, Katowice. 1998. Final Report for Bytom, Poland laboratory and site phytoremediation project.

Site Name	Caslano
Site Location	Caslano, Switzerland
Contaminant	Cadmium, copper, zinc
Vegetation Type	Basket willow (Salix viminalis)
Planting Descriptions	From cuttings, 4 cuttings per subplot (~1 sq m area subplots)
Media Type	Soil (acidic soil, pH 5.2)
Site Characterizations	
ET Rates	
Climate	
Mechanism	Phytoextraction
OM Requirements	Fertilization (120 kg P/ha, 200 kg K/ha, 40 kg N/ha), chelator amendments (Fe-rich Sequestren rapid, 24 kg Fe/ha), harvesting
Project Scale	Demonstration/ Pilot (four 1.0 x 1.0 m plots)
Project Status	Completed (1997-2001)
Cost	
Funding Source	
Initial concentrations	Cd: 2.8 mg/kg; Cu: 264 mg/kg; Zn: 1158 mg/kg (concentrations extractable with 2M nitric acid)
Final Concentrations	Total plant uptake: Cd: 47 g/ha; Zn: 14.5 kg/ha
Lessons Learned	
Comments	
Primary Contact	Catherine Keller, Swiss Federal Institute of Technology, catherine.keller@eplf.ch
Citation	Hammer, D; Kayser, A; Keller, C. 2003. Phytoextraction of Cd and Zn with Salix viminalis in field trials. Soil Use and Management. 19(2003): 187-192.

Site Name	Central Louisiana Wood Treatment Facility
Site Location	Louisiana
Contaminant	arsenic, chromium, PAH's, CCA, creosote
Vegetation Type	Loblolly pines
Planting Descriptions	all native vegetation removed and non-natives planted, hand planted, density of 500 per acre,
Media Type	soil, groundwater
Site Characterizations	groundwater contaminated with As, Cr, and PAHs up to 40 feet bgs; CCA and cresote mostly in 0-4 feet below ground surface
ET Rates	
Climate	
Mechanism	
OM Requirements	
Project Scale	Field demonstration (30 acres)
Project Status	Began Nov 1999
Cost	
Funding Source	
Initial concentrations	As: 1900 mg/kg, Cr: 2300 mg/kg, PAHs: 930 mg/kg
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Timothy Goist, Premier Environmental Services, Inc.; togoist@premiercorp-usa.com
Citation	2003 Phytotechnologies Conference Abstract

Site Name	C-H Plant Area: Texas City Chemicals
Site Location	Texas City, TX
Contaminant	Cadmium, Copper, Lead, other metals; high salinity (calcium, sodium, and magnesium chlorides)
Vegetation Type	Eucalyptus (Red River Gun, E. camadulensis), Salt Cedar
Planting Descriptions	From potted stock, whips
Media Type	Groundwater (red clay)
Site Characterizations	
ET Rates	35 gpd per tree
Climate	Temp range: 7 to 107 F; Elevation: 102 ft; Mean annual precip: 47"; Growing season: 3/17 to 11/14
Mechanism	Hydraulic Control
OM Requirements	
Project Scale	Demonstration/Pilot (27 acres)
Project Status	Ongoing
Cost	
Funding Source	BP; Texas Voluntary Cleanup Program
Initial concentrations	Salinity: approx 110 mmhos/cm
Final Concentrations	
Lessons Learned	
Comments	Quarterly monitoring of groundwater required for site. Sap flow measurements, tissue sampling, and root excavations also done.
Primary Contact	David Tsao, BP/Amoco, (630)836-7169, tsaodt@bp.com
Citation	ITRC Technologies Workshop 2004 and personal communication

Site Name	Firing Range, Chilliwack
Site Location	Chilliwack, BC
Contaminant	Lead, Copper
Vegetation Type	Garden Pea (Pisum sativum) and Indian Mustard (Brassica juncea)
Planting Descriptions	P. sativum was grown from seed, initially planted at a density of 200 seeds/ m^2 and were thinned to roughly 100 plants/m^2 shortly after germination. B. juncea was transplanted as a four week old seedling at a density of 25 plants/m2
Media Type	Soil (sandy clay)
Site Characterizations	
ET Rates	
Climate	Temp Range: 0 to 24 C; Elevation: 11 m; Mean annual precipitation: 1680 mm; Growing season: 4/6 to 11/9
Mechanism	Phytoextraction
OM Requirements	Fertilization, amendments (EDTA),
Project Scale	Demonstration/Pilot
Project Status	Completed (Summer 1999- Fall 2001)
Cost	
Funding Source	National Defence Canada, Environment Canada
Initial concentrations	Pb: Mean concentration 1018 mg/kg
Final Concentrations	Pb: Less than 500 ppm
Lessons Learned	Overall results suggest that *P. sativum* is a more effective phytoremediation tool than *B. juncea* for lead, and also that soil acidification has the potential to be as effective as low dose applications of EDTA in enhancing lead extraction. However, EDTA was still most effective in enhancing lead concentrations in shoot tissues. In most treatments throughout this study, metal concentrations ranging from <100 to 600 mg/kg were observed in shoot tissues. However, single dose applications of 1.7 mmol/kg EDTA resulted in shoot tissue concentrations exceeding 1000 mg/kg for both *B. juncea* and *P. sativum*. (EDTA applications ranged from 0.3 to 1.7 mmol/kg).
Comments	Phytoremediation compound was was equipped with a double-layer geomembrane liner, overflow trench, and perimeter fence.
Primary Contact	Peat moss added as a bulking agent, at a rate providing a 10% volume increase to the top eight inches of the experimental soil. Granular fertilizer (28-10-10) was distributed at a rate of 25 kg per hectare. Some treatments received EDTA at a rate of 0.03 mmol/kg soil 50 days after planting.
Citation	Phytoremediation of Lead Contaminated Rifle Range Soils, CFB Chilliwack, BC. RMC-CCE-ES-00-13. Environment Canada, 2000.

Site Name	Cobalt
Site Location	Cobalt, ON
Contaminant	Arsenic
Vegetation Type	Ryegrass
Planting Descriptions	
Media Type	
Site Characterizations	Depth to groundwater varies, approximately 3 to 20 feet on average.
ET Rates	
Climate	Temp Range: -40 to 35.4 C; Elevation: 252 m; Mean annual precipitation: 855.6 mm; Growing season: 5/17 to 9/25
Mechanism	Phytoaccumulation
OM Requirements	None
Project Scale	Demonstration/Pilot (0.5 acres)
Project Status	Completed
Cost	$12,000 CAN, approximately $9,120 US
Funding Source	
Initial concentrations	As: 10-100 mg/Kg in tailings
Final Concentrations	
Lessons Learned	Mine tailings would rapidly dry out and maintain high salt concentrations that did not promote vegetative growth. However, a successful pilot-scale operation may have resulted had the hydrological status been controlled and/or another species of grass wa
Comments	
Primary Contact	Robert Tossell, CH2M Hill, Bob.Tossell@ch2m.com
Citation	

Site Name	Combustion Superfund
Site Location	Denham Springs, LA
Contaminant	1,2-dichloroethane, polychlorinated biphenyls, benzene, lead, mercury, nickel, silver, toluenediisocyante, toluene diamine
Vegetation Type	Eucalyptus, Poplar, Native Willows
Planting Descriptions	Potted Stock
Media Type	Groundwater
Site Characterizations	5-10' depth of impact
ET Rates	
Climate	Temperature Range: -8 to 102 F; Elevation: 59 ft; Mean annual precipitation: 60.8"; Growing season: 3/18 to 11/4
Mechanism	Hydraulic control, rhizodegradation, phytovolatilization
OM Requirements	
Project Scale	Full-Scale
Project Status	planted 2002
Cost	
Funding Source	Superfund
Initial concentrations	Combustion Superfund
Final Concentrations	
Lessons Learned	
Comments	5-10 ft (depth of impact)
Primary Contact	Katrina Coltrain, US EPA (214) 665-8143 Todd Thibodeaux, LDEQ (225) 219-3225
Citation	LDEQ, EPA6

Site Name	Craney Island Fuel Terminal
Site Location	Portsmouth, VA
Contaminant	Diesel fuel, lead, other petroleum compounds (TPH)
Vegetation Type	Bermuda grass, rye grass, white clover, tall fescue
Planting Descriptions	Seeding
Media Type	Soil (21% silt, 19% clay, 2.5 meq/L sand)
Site Characterizations	Phytoremediation on biological treatment cell containing 12 - 18 inch (30.5 - 45.7 cm) layer of contaminated soil followed by a sand layer, followed by a polyethylene liner, another sand layer, a geogrid liner, and finally, a compacted clay base.
ET Rates	
Climate	Temperature Range: -3 to 104 F; Elevation: 26 ft; Mean annual precipitation: 44.6"; Growing season: 4/6 to 10/31
Mechanism	Rhizodegradation
OM Requirements	Monthly basis: Wedding, mowing, fertilization (50 lbs N/acre, 25 lbs P/acre). TPH and nutrient sampling monthly or bimonthly. Tilling and irrigation when necessary. Reseeding of fescue and clover in 1996.
Project Scale	Demonstration/Pilot (120 ft x 180 ft)
Project Status	Completed (1995-1997)
Cost	
Funding Source	AATDF(Advanced Applied Technology Demonstration Facility) and DOD (Department of Defense)
Initial concentrations	
Final Concentrations	
Lessons Learned	Total TPH degradation in soils varied by vegetative treatment. November 1996 data: Bermuda=31% TPH reduction in soils; fescue=35%; clover=37%; unvegetated=25%
Comments	
Primary Contact	M. K. Banks, Purdue University (765) 496-3424, kbanks@ecn.purdue.edu
Citation	Banks, M. Katherine, A. Paul Schwab, and R.S. Govindaraju. Phytoremediation of Soil Contaminated with Hazardous Organic Chemicals (1997): 5 pg. Online. Internet. 1 July 1998. Available: http://www.ruf.rice.edu/~aatdf/pages/phyto.htm.

Site Name	Danbury, CT brownfields site (Abandoned Hat Factory)
Site Location	Danbury, CT
Contaminant	Hg
Vegetation Type	Eastern Cottonwood
Planting Descriptions	Genetically modified cottonwoods
Media Type	Soil (primarily fill)
Site Characterizations	Groundwater 7 ft. bgs
ET Rates	
Climate	Temperature Range: -26 to 102 F; Elevation: 378 ft; Mean annual precipitation: 51.9"; Growing season: 5/15 to 9/22
Mechanism	Phytovolatilization
OM Requirements	Irrigation, weeding, visual inspections and monitoring
Project Scale	Demonstration/Pilot (1/3 acre)
Project Status	Ongoing (7/2003-fall 2004)
Cost	
Funding Source	USEPA Grant, City of Danbury
Initial concentrations	Hg: up to 1500 ppm
Final Concentrations	
Lessons Learned	
Comments	Pilot through 2004. If results are positive, then phytoremediation may be applied to whole site
Primary Contact	David Glass, Applied Phytogenetics, 617-653-9945, dglass@appliedphytogenetics.com; Jack Kozuchowski, Danbury Health Dept, 203-797-4625, J.Kozuchowski@ci.danbury.ct.us
Citation	Documents not yet available. Referenced in memo to US EPA.

Site Name	Dearing, KS Phytostabilization Demonstration
Site Location	Dearing, KS
Contaminant	Pb, Zn, Cd
Vegetation Type	Hybrid poplars (4 Ecolotree varieties including D01, PC1, OP367, and Imperial Carolina)
Planting Descriptions	First planted June 1994 (93% did not survive), replanted March 1995 (after removing all previously planted trees). Planted as 120 cm whips, deep-trenched (15 cm wide x 1 m deep). Trenches amended with N (11 g/m trench), P (23 g/m), K (11 g/m), and limestone (1 kg/m). Half of plots were amended with cattle manure. Each plot consisted of 24 trees planted in three adjacent rows of eight trees. Trees planted one meter apart within rows and rows were 1.5 mapart. Three replications used for a total of 24 plots.
Media Type	Soil (smelter slag residue, finer than soils at Galena)
Site Characterizations	Contaminant concentrations highly stratified
ET Rates	D01: 26.69 mmol/(m2-s); PC1: 25.85 mmol/(m2-s); OP367: 20.93 mmol/(m2-s); Imperial Carolina: 23.51 mmol/(m2-s)
Climate	Temperature Range: -13 to 111 F; Elevation: 770 ft; Mean annual precipitation: 43.7"; Growing season: 4/26 to 10/13
Mechanism	Phytostabilization, phytoextraction
OM Requirements	Manure amendments. After tree establishment, no management needed.
Project Scale	Demonstration/Pilot (1 acre)
Project Status	Completed (1994-1998)
Cost	
Funding Source	Great Plains/ Rocky Mtn Hazardous Substance Research Center
Initial concentrations	Zn: 47,223 mg/kg (top 15 cm of soil), decreasing down to 2828 mg/kg (75-90 cm); Pb: Ranged between 40 and 14134 mg/kg (declining with depth); Cd: 4.6-108 mg/kg (declining with depth)
Final Concentrations	
Lessons Learned	Overall poplar survival rate ranged between 18-53%, possibly attributed to Zn phytotoxicity. There were higher concentrations of contaminants than in Galena study and contaminants highly stratified. Manure amendments generally increased poplar survivability. Transpiration rates were higher for manure-treated trees. Imperial Carolina hybrids have twice rate of photosynthesis of other varieties and highest water use efficiency and are recommended species for site remediation. Metal concentrations in plants decreased in order of leaves>bark>twigs>wood for Zn and Cd, and bark>wood>twig=leaves for Pb (see Pierzynski, 2002 for details).
Comments	
Primary Contact	G. Pierzynski, Kansas State University, 785-532-7209, gmp@ksu.edu
Citation	Pierzynski, GM; Schnoor, JL; Youngman, A; Licht, L; Erickson, LE. 2002. Poplar Trees for Phytostabilization of Abandoned Zinc-Lead Smelter. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management. 6(3):177-183 Phytostabilization Demonstration, One Acre Test Plot Abandoned Smelter, Barren Land, Phytoremediation: Technology Evaluation Report. GWRTAC TE-98-01 (p 8)

Site Name	Dorchester, MA
Site Location	Dorchester, MA
Contaminant	Lead
Vegetation Type	Indian mustard, sunflower
Planting Descriptions	Planted from seeds
Media Type	Soil (sandy loam)
Site Characterizations	
ET Rates	
Climate	Temperature Range: -7 to 102 F; Elevation: 30 ft; Mean annual precipitation: 41.5"; Growing season: 5/3 to 10/5
Mechanism	Phytoextraction
OM Requirements	Irrigation, fertilization, liming, harvesting, pesticides, EDTA amendment
Project Scale	Demonstration/ Pilot (1200 sq ft)
Project Status	Completed (1996-1998)
Cost	
Funding Source	Phytotech
Initial concentrations	Pb: varied less than 400 to greater than 1000 ppb
Final Concentrations	Pb: less than 800 ppb
Lessons Learned	
Comments	
Primary Contact	Michael Blaylock, Edenspace, (703) 961-8700, blaylock@edenspace.com
Citation	Blaylock, MJ. 2000. Field Demo of Phytoextraction of Lead Contaminated Soils. Phytoremediation of Contaminated Soil and Water. Ed: Terry, Norman and Banuelos, GS. CRC Press.

Site Name	Dornach
Site Location	Dornach, Switzerland
Contaminant	Cadmium, copper, zinc
Vegetation Type	Basket willow (Salix viminalis)
Planting Descriptions	From cuttings, 2-4 cuttings per subplot (~1 sq meter area subplots)
Media Type	Soil (calcerous, pH 7.3)
Site Characterizations	
ET Rates	
Climate	
Mechanism	Phytoextraction
OM Requirements	Fertilization (120 kg P/ha, 200 kg K/ha, 40 kg N/ha), chelator amendments (Fe-rich Sequestren rapid, 24 kg Fe/ha), sulfur (36 mol/m2), harvesting
Project Scale	Demonstration/ Pilot (four 1.1 x 1.1 m plots)
Project Status	Completed (1997-2001)
Cost	
Funding Source	
Initial concentrations	Cd: 2.3 mg/kg; Cu: 550 mg/kg; Zn: 650 mg/kg (concentrations extractable with 2M nitric acid)
Final Concentrations	Total plant uptake: Cd: 170-194 g/ha; Zn: 13.4-17 kg/ha
Lessons Learned	
Comments	
Primary Contact	Catherine Keller, Swiss Federal Institute of Technology, catherine.keller@eplf.ch
Citation	Hammer, D; Kayser, A; Keller, C. 2003. Phytoextraction of Cd and Zn with Salix viminalis in field trials. Soil Use and Management. 19(2003): 187-192.

Site Name	East Palo Alto
Site Location	East Palo Alto, CA
Contaminant	Arsenic, sodium
Vegetation Type	Eucalyptus, Tamarisk
Planting Descriptions	Planted as 5 gal trees with 4-5 foot centers, some shoots and cuttings. Tight planting density.
Media Type	Soil (clayey soil on top, over more porous sand layer)
Site Characterizations	Groundwater containment inside slurry wall. Groundwater 4-5 ft bgs.
ET Rates	
Climate	Temperature Range: 27 to 105 F; Elevation: 39 ft; Mean annual precipitation: 13.8"; Growing season: 1/24 to 12/28
Mechanism	Phytoextraction
OM Requirements	Soil treatment prior to planting, fertilization (N and K), irrigation (during 1st 6 months, then ceased), Mulching (wood chips), Pest control (ladybugs released to control psyllids), replanting after 1st year but then unnecessary
Project Scale	Full-Scale (1 acre)
Project Status	Operational (began 1981)
Cost	$4000/ yr; < 50,000 plant installation
Funding Source	Private
Initial concentrations	Arsenic: 0.05-200 mg/l; sodium: 5000mg/l
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	Mike Rafferty, SS Papadopulous and Associates, 415-896-9000 ext. 202, mrafferty@sspa.com
Citation	Five Year Status Report: 1990 Bay Road Site, East Palo Alto, CA. March 31, 2004. Prepared by Geomatrix Consultants, Inc. in association with S.S. Papadopulos & Associates, Inc.

Site Name	Ecological Experimental Station of Red Soil, China
Site Location	Yingtan, Jangxi Province, China
Contaminant	Cadmium, lead, zinc
Vegetation Type	Vetiver grass
Planting Descriptions	
Media Type	Soil (red soil-oxisoil)
Site Characterizations	
ET Rates	
Climate	
Mechanism	Phytoextraction
OM Requirements	Fertilization
Project Scale	Demonstraton/ Pilot
Project Status	Completed
Cost	
Funding Source	
Initial concentrations	
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	HM Chen, Chinese Academy of Sciences, PO Box 821, Nanjing, 210008, China
Citation	
Site Name	Chen, HM; et al. 2000. Chemical methods and phytoremediation of soil contaminated with heavy metals. Chemosphere. 41(2000): 229-234

Site Name	Ensign-Bickford Company
Site Location	Simsbury, CT
Contaminant	Lead
Vegetation Type	Indian mustard (Brassica juncea) and sunflower (Helianthus annus)
Planting Descriptions	Seeded with three treatment crops
Media Type	Soil (silty loam)
Site Characterizations	Water table 2-4 ft bgs. Poor site drainage. Soil saturated throughout growing seasons (April-October)
ET Rates	
Climate	Temperature Range: -26 to 102 F; Elevation: 174 ft; Mean annual precipitation: 44.1"; Growing season: 5/12 to 9/23
Mechanism	Phytoextraction, phytostablilization
OM Requirements	Irrigation; fertilization with N, P, K (tilled to 15-20 cm depth) and foliar fertilizers via irrigation system; dolomite lime added to adjust pH (tilled to 15-20 cm depth); stabilizing amendments added to Area 5.
Project Scale	Full scale (2.35 acres)
Project Status	Completed (April-Oct 1998)
Cost	
Funding Source	
Initial concentrations	Pb concentrations for Area 1: 500-5000 mg/kg; Area 2: 125-1250 mg/kg; Area 3: 500-2000 mg/kg; Area 4: 750-1000 mg/kg; Area 5: 6.5-7.5 mg/kg. Average Pb concentration: 635 mg/kg.
Final Concentrations	Average Pb concentration: 478 mg/kg (Area 1-4).
Lessons Learned	Lead uptake ranged from 342 mg/kg in Indian mustard in treatment crop 1 to 3252 mg/kg in Indian mustard in treatment crop 3. Average lead uptake in sunflower similar, approximately 1000 mg/kg.
Comments	Plant growth for treatment crops generally good, although some areas remained saturated and thus exhibited poor plant growth and reduced biomass yields.
Primary Contact	Michael Blaylock, Edenspace Systems Corp, (703) 390-1100, SoilRx@aol.com
Citation	FRTR. 2000. Phytoremediation at the Open Burn and Open Detonating Area, Ensign-Bickford Company, Simsbury, CT. Abstracts of Remediation Case Studies, Volume 4. EPA 542-R-00-006. June 2000

Site Name	Fort Dix, NJ
Site Location	Fort Dix, NJ
Contaminant	Lead
Vegetation Type	Indian mustard, sunflower, mixed grasses
Planting Descriptions	Seeding
Media Type	Soil (predominantly sand)
Site Characterizations	
ET Rates	
Climate	Temperature Range: -4 to 102 F; Elevation: 130 ft; Mean annual precipitation: 44"; Growing season: 4/15 to 10/23
Mechanism	Phytoextraction
OM Requirements	Irrigation (with leachate containing EDTA, lead)
Project Scale	Demonstration/ Pilot (1.25 acres)
Project Status	Completed 1997- 10/2002
Cost	
Funding Source	Superfund
Initial concentrations	Pb: 515 mg/kg (range: 160-10,000 mg/kg)
Final Concentrations	Pb: 290 mg/kg
Lessons Learned	Project goals (reduction of Pb below 400 mg/kg) were met. However, the amount of phytoextracted lead did not account for the difference in initial and final lead concentrations
Comments	Excavated lead fragments prior to planting. 3500 tons of soil placed in 12 inch deep phytocells. 111,000 gallons of recicrulated drainage water remained at end of demonstration with soil lead concentration of 30 mg/kg
Primary Contact	Steve Rock, USEPA, 513-569-7149, rock.steven@epa.gov
Citation	Rock, Steve. 2003. Field Evaluations of Phytotechnologies. Phytoremediation: Transformation and Control of Contaminants. Ed: Steven C. McCutcheon and Jerald. L. Schnoor. 2003 John Wiley and Sons, Inc.

Site Name	Galena, KS field study
Site Location	Galena, KS
Contaminant	Cadmium, Lead, Zinc from "chat" waste
Vegetation Type	tall fescue
Planting Descriptions	Planted via seeding
Media Type	Soil (coarse, sandy loam)
Site Characterizations	5% graded slope; chat primarily chert, and on average composed of 81% sand-sized, 13% silt-sized, and 6% clay-sized particles by weight.
ET Rates	
Climate	Temperature Range: -13 to 111 F; Elevation: 941 ft; Mean annual precipitation: 44.5"; Growing season: 4/26 to 10/13
Mechanism	Phytostabilization, phytoextraction
OM Requirements	Amendments (inoculation with mycorrhiza, treatment with Benomyl fungicide, manure amendment), reseeding (1996)
Project Scale	Demonstration/Pilot
Project Status	Completed (seeded in Fall 1995, 5 years)
Cost	
Funding Source	Great Plains/ Rocky Mtn Hazardous Substance Research Center
Initial concentrations	Cd: 53 mg/kg; Pb: 2050 mg/kg; Zn: 22690 mg/kg
Final Concentrations	Cd: 81 mg/kg (higher due to anaytical error?); Pb: 2079 mg/kg; Zn: 20680 mg/kg
Lessons Learned	Concentrations of Cd, Pb, Zn in fescue uninfluenced by treatments. No indication that inoculation of mycorrhizal fungi was successful. Vegetative cover decreased over time, despite intial promotion of growth by manure, perhaps due to Zn phytotoxicity. Manure applications generally decreased exchangeable forms of metals and increased organic forms. Exchangeable forms of Pb and Zn generally increased while residual forms decreased during 1st and 3rd years of study, probably due to soil acidification over the same period.
Comments	Fescue selected after result of greenhouse studies. Three different seeded treatments: manure-amended and seeded control; manure amended, seeded, and mycorrhizal-inoculated treatment; and manure-amended, seeded treatment with Benomyl fungicide.
Primary Contact	G. Pierzynski, Kansas State University, 785-532-7209, gmp@ksu.edu
Citation	Pierzynski, GM; Lambert, M; Hetrick, BAD; Sweeney, DW; Erickson, LE. 2002. Phytostabilization of Metal Mine Tailings Using Tall Fescue. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management. 6(4): 212-217. Also see US EPA STAR Grant R825549C047.

Site Name	Unnamed Gary, IN site
Site Location	Gary, IN
Contaminant	Arsenic, lead
Vegetation Type	bulrush, sedges, cattails, arrowhead
Planting Descriptions	Native species used
Media Type	Soil (sandy loam, submerged)
Site Characterizations	
ET Rates	
Climate	Lake Michigan/ Harbor area climate. Temperature Range: ; Elevation: ft; Mean annual precipitation: "; Growing season:
Mechanism	Phytostabilization (As, Pb), Phytoextraction (As)
OM Requirements	Irrigation, fertilization
Project Scale	Demonstration/ pilot (3 acres)
Project Status	Ongoing (began 5/2002)
Cost	unfunded
Funding Source	not applicable
Initial concentrations	As: approx. 2000 mg/kg; Pb: approx. 2000 mg/kg
Final Concentrations	
Lessons Learned	Results are still somewhat premature because this is in progress. However, it was immediately recognized that high phosphate applications released As from the sediments and into the water. It increases As bioavailability but also increased mobility.
Comments	
Primary Contact	Paul Schwab, Purdue University, (765)-496-3602, pschwab@purdue.edu
Citation	

Site Name	Jones Island Confined Disposal Facility
Site Location	Milwaukee, WI
Contaminant	Anthracene, PCBs, heavy metals
Vegetation Type	Populus deltoides (tree) Tripsacum dactyloides (grass) Sesbania exultata (vetch) Carex microptera (sedge) or Andropogon gerardii (grass) Juncusus effusus (rush) or Helianthus grosserratus (sunflower) potentially Morus rubra or Morus alba (trees)
Planting Descriptions	From seeds, hand planted
Media Type	Sediment, silty loam
Site Characterizations	
ET Rates	
Climate	Mostly sunny during the day. Temp range: -26 to 103 F; Elevation: 672 ft; Mean annual precip: 32.9"; Growing season: 5/20-9/26
Mechanism	Rhizodegradation
OM Requirements	Fertilization, Harvesting
Project Scale	Demonstration/Pilot (2744 cu ft)
Project Status	Ongoing
Cost	
Funding Source	
Initial concentrations	Concentration results available Fall '04
Final Concentrations	Concentration results available Fall '04
Lessons Learned	
Comments	The project has just started so the total cost can not be estimated as their are probably more expenses to come. We are not yet sure what fraction of the plants will have to be replanted but are quite sure that we will need to seed again.
Primary Contact	Katy Euliss, Purdue University, 765-496-2211, keuliss@purdue.edu
Citation	

Site Name	Leadwood Chat Tailings
Site Location	Desloge, MO
Contaminant	Cadmium, lead, zinc
Vegetation Type	Tall fescue
Planting Descriptions	40 plots (4 rows, each row with one of three amendments or control, with 10 plots per row); seeded
Media Type	Soil (coarse tailings from coarse milling and gravity separation of metals from ore)
Site Characterizations	Bulk density of tailings intially 1.77 to 1.90 grams per cubic centimeter (average 1.82 g/cm3)
ET Rates	
Climate	Temperature Range: -18 to 107 F; Elevation: 805 ft; Mean annual precipitation: 37.5"; Growing season: 4/30 to 10/8
Mechanism	Phytoextraction
OM Requirements	Fertilization, weeding, irrigation, harvesting, addition of organic soil amendements (milorganite, ormiorganics compost, St. Peters compose)
Project Scale	Demonstration/Pilot (7704 square feet)
Project Status	Completed (2000-2002) but monitoring may be extended
Cost	Demonstration cost: $17,200 per acre; full scale estimate: $5000-$15,000 per acre (variation due to cost of compost)
Funding Source	US EPA Mine Waste Technology Program
Initial concentrations	
Final Concentrations	
Lessons Learned	None of the soil amendments evaluated exhibited long-term compliance with the three plant performance objectives. However, the St. Peters Compost high application rate treatment came closest as it.
Comments	MSE recommends the following: that the amendment rates used were insufficient for meeting the study objectives. Acid-extractable metals levels in rooting zone soils were generally 1.5- to 2-fold greater than those observed at BRMTS, which may translate to higher plant available metal concentrations as well (up to their respective solubility limits). Thus, it is hypothesized that at application rates of greater than 2-fold, the St. Peters Compost high application rate treatment rate may be necessary to meet the present objectives for successful site reclamation. Furthermore, the Ormiorganics high application rate treatment results at BRMTS were sufficiently encouraging to justify elevated rates of applying this amendment at LCTS as well
Primary Contact	Darcy Byrne-Kelly, MSE Technology, (406) 494-7419, dbyrne@mse-ta.com
Citation	Revegetation of Mining Waste Using Organic Soil Amendments and Evaluation of the Potential for Creating Attractive Nusiances for Wildlife. Abstract. 2001. Proceedings of the 2001 Conference on Environmental Research.

Site Name	Lechang Pb/Zn mine tailings
Site Location	Lechang City, Guangdong Province, China
Contaminant	Cadmiu, copper, lead, zinc
Vegetation Type	Vetiver grass (V. zizanioides), Sesbiana species (S. sesban, S. rostrata)
Planting Descriptions	Planted as seedlings
Media Type	Soil
Site Characterizations	tailings pond (dry surface)
ET Rates	
Climate	Subtropical climate. Mean annual precipitation: 1500 mm
Mechanism	Phytoextraction
OM Requirements	Fertilization, harvesting, irrigation
Project Scale	Field trial
Project Status	Completed
Cost	
Funding Source	
Initial concentrations	Zn: 4388 mg/kg, Pb: 4164 mg/kg; Cu: 35 mg/kg; Cd: 32 mg/kg
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	MH Wong, Hong Kong Baptist University, +852-3411-7743, mhwong@hkbu.edu.hk
Citation	Yang, B, et. al. 2003. Growth and metal accumulation in vertiver and two Sesbania species on lead/ zinc mine tailings. Chemosphere. 52(2003): 1593-1600

Site Name	Magic Marker
Site Location	Trenton, NJ
Contaminant	Lead
Vegetation Type	Indian Mustard (Brassica juncea) and sunflower
Planting Descriptions	Planted from seeds
Media Type	Soil (shallow, loamy sand)
Site Characterizations	
ET Rates	
Climate	Temperature Range: -4 to 102 F; Elevation: 190 ft; Mean annual precipitation: 42"; Growing season: 4/15 to 10/23
Mechanism	Phytoextraction
OM Requirements	amended with EDTA, harvested, replanted
Project Scale	Full-Scale (0.25 acres, 1 acre, 4500 sq ft)
Project Status	Operational (planted 1996)
Cost	$200,000 (EPA); $109,408 (NJ preliminary investigation)
Funding Source	EPA brownfield grant; NJ State Hazardous Discharge Site Remediation Fund
Initial concentrations	Pb: 500 to 1000 ppm, 200 to 1800 mg/kg
Final Concentrations	Pb: 51 grams removed from treatment plot
Lessons Learned	Indian mustard uptake was 830 mg/kg (1st crop) and 2300 mg/kg (2nd crop); sunflower uptake around 400 mg/kg. However, uptake did not account for total soil reduction, which estimated to be around 4%.
Comments	
Primary Contact	Michael Blaylock, Edenspace, (703) 961-8700, blaylock@edenspace.com
Citation	US EPA. 2001. Phytoextraction of lead in soils at Magic Marker and Ft. Dix. Innovative Technology Evaluation Report, US EPA. National Risk Management Research Laboratory, Cincinatti, OH

Site Name	Metal Plating Facility
Site Location	Findlay, OH
Contaminant	Chromium, cadmium, nickel, zinc, lead, trichloroethylene
Vegetation Type	Hybrid Poplar, Ryegrass; Indian mustard
Planting Descriptions	30 trees, deep rooted and planted when 10-16 ft tall
Media Type	Soil (silt loam)
Site Characterizations	GW 10-15' bgs
ET Rates	
Climate	Temp range: -19 to 104 F; Elevation: 804 ft; Mean annual precip: 34.5"; Growing season: 5/19 to 9/24
Mechanism	Phytoextraction, Hydraulic Control
OM Requirements	sampling groundwater
Project Scale	Full-Scale (10,000 sq ft)
Project Status	Operational/In Progress. Planted 1997
Cost	
Funding Source	State, voluntary
Initial concentrations	TCE: up to 150 mg/L
Final Concentrations	
Lessons Learned	Dramatic drop, on average, of 30 ppm to less than 5 ppm. However, the source area continues to supply site with contaminants
Comments	SITE Program. Trees have grown at a rate of 4-8 ft/year. Results of the first 3 years indicated significant reduction of TCE concentrations in the aquifer in addition to demonstration of hydraulic effects on groundwater flow
Primary Contact	Michael Blaylock, Edenspace, (703) 961-8700, blaylock@edenspace.com or Edd Gatliff, Applied Natural Sciences, (513) 895-6061 ans@fuse.net
Citation	Phytoremediation of TCE in Groundwater using Populus. http://www.clu-in.org/products/phytotce.htm

Site Name	Former Orchard Site
Site Location	Picatinny Arsenal, New Jersey
Contaminant	Arsenic (from arsenical pesticides)
Vegetation Type	Brake Fern (Pteris: mayil, parkeril, vittata)
Planting Descriptions	Transplanted from pots, 12 and 6 inch planting density
Media Type	Soil (loam soil)
Site Characterizations	Groundwater >20 feet below ground surface
ET Rates	
Climate	Temperature Range: -4 to 102 F; Elevation: 171 ft; Mean annual precipitation: 45.9"; Growing season: 4/15-10/26
Mechanism	Phytoextraction
OM Requirements	Irrigation, lime amendments, harvesting, and fertilizer
Project Scale	Demonstration plots (10,000 sq ft)
Project Status	Ongoing (2001)
Cost	
Funding Source	US Army
Initial concentrations	As: 10 ppm to 60-70 ppm
Final Concentrations	
Lessons Learned	
Comments	Original turf grass was removed. A greenhouse was constructed on site for overwintering ferns
Primary Contact	Michael Blaylock, Edenspace, (703) 961-8700, blaylock@edenspace.com
Citation	Report available Fall '04 from Edenspace

Site Name	Palmerton Zinc Pile Demo (Blue Mountain)
Site Location	Palmerton (Carbon County), PA
Contaminant	Zinc, cadmium
Vegetation Type	Alpine Pennycress, Bladder Campion
Planting Descriptions	Hydroseeding
Media Type	Soil; manufactured soil (blend of treated municipal solids, power plant fly ash, and agricultural limestone)
Site Characterizations	Very steep slopes, mountainous topography. Zinc pile is cinder bank, 2.5 miles long, 200 feet high and 500-1000 ft wide. Drains to Aquashicola Creek and eventually Lehigh River.
ET Rates	
Climate	Temperature Range: -12 to 105 F; Elevation: 1500 ft; Mean annual precipitation: 43.5"; Growing season: 5/5 to 10/2
Mechanism	Phytostabilization, Phytoextraction
OM Requirements	Amendment application using spreader trucks
Project Scale	Demonstration/Pilot (25 sq meters)
Project Status	Completed (1986)
Cost	Estimated as $100,000 feasibility study
Funding Source	PRP
Initial concentrations	Zinc: 35000-80000 mg/kg
Final Concentrations	N/A
Lessons Learned	Determined manufactured soil performed best when not overly blended. Site could withstand storms as great as 2.9"/hr in 2 hours, or 8.5" rain/hr in 20 hrs. Manufactured soil would be surface-applied, containing limestone and seed, and unmulched. Best ratio for woody plants 3:1 (biosolids: flyash). Best ratio for grass/legumes is 1:1 (biosolids: flyash). Ratio selected for full scale is 2:1 (biosolids:flyash). Dominant grass species for mixed seed is 'Oahu' intermediate wheatgrass.
Comments	
Primary Contact	S. L. Brown; Rufus Chaney USDA, (301) 504-6511, chaneyr@ba.ars.usda.gov
Citation	Oyler, J. Blue Mountain Superfund Remediation Project, Palmerton, PA. Powerpoint presentation. June 10, 2004. ITRC Phytotechnologies conference.

Site Name	Palmerton Zinc Pile (Blue Mountain)
Site Location	Palmerton (Carbon County), PA
Contaminant	Zinc, cadmium
Vegetation Type	Oahe intermediate wheatgrass, Pennfine perennial ryegrass, empire birdsfoot trefoil, ruebans Canada bluegrass, and Streeker redtop
Planting Descriptions	Manufactured soils contained seeds already in it and was spread uniformly using trucks on terraced roads
Media Type	Soil; manufactured soil (blend of treated municipal solids, power plant fly ash, and agricultural limestone)
Site Characterizations	Very steep slopes, mountainous topography. Zinc pile is cinder bank, 2.5 miles long, 200 feet high and 500-1000 ft wide. Drains to Aquashicola Creek and eventually Lehigh River.
ET Rates	
Climate	Temperature Range: -12 to 105 F; Elevation: 1500 ft; Mean annual precipitation: 43.5"; Growing season: 5/5 to 10/2
Mechanism	Phytostabilzation, phytoextraction
OM Requirements	2:1 biosolids:flyash amendments
Project Scale	Full Scale (1000 acres; 1000 more acres proposed)
Project Status	Completed (1991-1995)
Cost	$1,249,262 (EPA, OU1)
Funding Source	PRP
Initial concentrations	Zinc: 35000-80000 mg/kg
Final Concentrations	
Lessons Learned	All water leaving treated areas of mountain is in compliance with NPDES Limits for pH, zinc, cadmium, lead, TDS, TSS and no further treatment is required to discharge
Comments	This is a reclamation site using biosolids and vegetative cover. Not really phytoremediation site although phytoremediation processes are taking place.
Primary Contact	John Oyler, oylers@ptd.net
Citation	Oyler, J. Blue Mountain Superfund Remediation Project, Palmerton, PA. Powerpoint presentation. June 10, 2004. ITRC Phytotechnologies conference.

Site Name	Port Colborne
Site Location	Port Colborne, ON
Contaminant	Arsenic, cobalt, copper, and nickel are contaminants of concern (Site of former Ni refinery)
Vegetation Type	Corn, soybeans, radish, oats, alyssum
Planting Descriptions	From seeds, hand planted
Media Type	Soil (4 types used in demonstration: sandy, high & low clay, high organic peaty)
Site Characterizations	7 to 11 feet (depth to groundwater)
ET Rates	
Climate	Temperature Range: -26 to 33.5 C; Elevation: 175 m; Mean annual precipitation: 854.1 mm; Growing season: 5/20-9/23
Mechanism	Phytostabilization
OM Requirements	Amendment of dolimitic limestone (80-100 tons per hectare)
Project Scale	Demonstration/Pilot (4 field sites, 30x50 m)
Project Status	Ongoing (2001-2003)
Cost	Several million $
Funding Source	
Initial concentrations	n/a
Final Concentrations	n/a
Lessons Learned	
Comments	Purpose of the phytostabilization part of the project is determine levels of the liming agent that will mitigate any adverse effects of the CoCs. 20 metals are being evaluated in very great detail. Four crop plants (corn, soybeans, radish and oats) are involved in the phytostabilization testing though there has been some nickel phytoextraction testing carried out with alyssum in conjunction with it.
Primary Contact	James Higgins, Jacques Whitford Environment, 905-469-2475, jhiggins@jacqueswhitford.com
Citation	

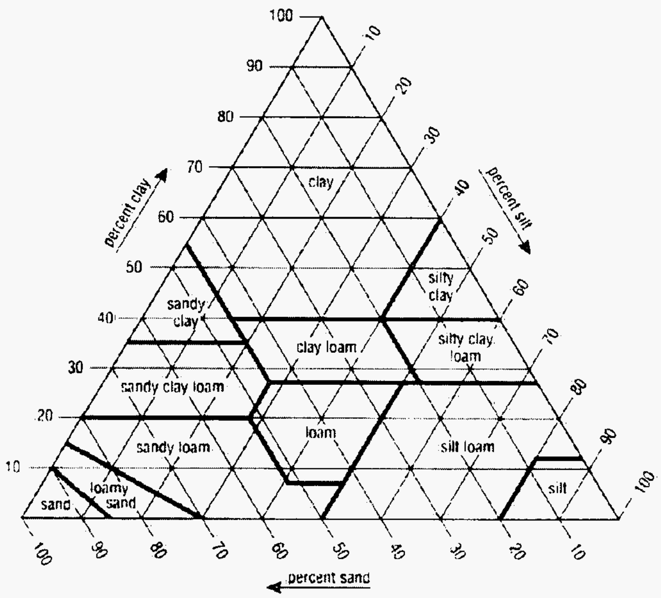
Site Name	Savannah River, SC
Site Location	Aiken, SC
Contaminant	Cadmium, Chromium, Vanadium
Vegetation Type	Bush beans (Phaseolus vulgaris)
Planting Descriptions	Planted in three consecutive years (1, 15, and 27 months after metals treatment to soils). Final spacing of 76 cm between rows and 10 cm between plants
Media Type	Soil (fine loamy and loamy siliceous sands)
Site Characterizations	
ET Rates	
Climate	Abundant rainfall. Warm, humid conditions prevail. Temp range: -1 to 108; Elevation: 134 ft; Mean annual precip: 44.6"; Growing season: 4/15 to 10/23
Mechanism	Phytoextraction
OM Requirements	Mowing, fertilization, irrigation, weeding, lime amendments (pH adjustment), tilling
Project Scale	Demonstration/ Pilot
Project Status	1987-1992
Cost	
Funding Source	US DOE
Initial concentrations	
Final Concentrations	
Lessons Learned	There was little vertical movement of Cd and V after 30 months, and somewhat greater movement of Tl. During the first 18 months, there were large reductions in extractable amounts of metals, with very little change detected in the subsuquent 12 months. Adter 18 months, the Cd, Tl, and V applied were probably transformed to forms less available for uptake.
Comments	Metals added to site five years prior to planting: 11.2 kg/ha Cd, 5.6 kg/ha Tl, and 5.6 kg/ha V.
Primary Contact	HW Martin, Savannah River Ecology Laboratory, University of Georgia, hawmartin@aol.com
Citation	Martin, H.W. and D.I. Kaplan. 1998. Temporal changes in cadmium, thallium, and vanadium mobility in soil and phytoavailability under field conditions. Water, Air, and Soil Pollution 101:399-410. See also 1996 *Plant and Soil* article

Site Name	Spring Valley (former Army ammunition site)
Site Location	Washington, DC
Contaminant	Arsenic
Vegetation Type	hyperaccumulating fern (Pteris)
Planting Descriptions	Ferns transplanted from pots
Media Type	Soil
Site Characterizations	Mixed clay loam and sandy loam
ET Rates	
Climate	
Mechanism	Temperature Range: -5 to 104 F; Elevation:16 ft; Mean annual precipitation: 38.6"; Growing season: 4/10-10/31
OM Requirements	Phytoextraction
Project Scale	Irrigation, shade cloths installed, fertilization, lawn removed prior to installation
Project Status	Demonstration/Pilot (3 sites with total area = 2500 sq ft.)
Cost	Ongoing (began May 2004)
Funding Source	Army Corps of Engineers
Initial concentrations	As: 20-150 ppm
Final Concentrations	
Lessons Learned	
Comments	
Primary Contact	
Citation	Michael Blaylock, Edenspace, (703) 961-8700, blaylock@edenspace.com
Site Name	

Appendix E: USDA Soil Classification System
(adopted from the 1993 USDA Soil Survey Manual)

For most sites, soil particles in the contaminated medium were less than 2 mm, and the following soil texture classification system was used. Sites containing a contaminated soil medium of larger particle sizes (i.e. rock fragments) or manufactured soils were described using language found in the site literature or documentation, or in reference to USDA manual.

Figure 1. Sand, clay, and silt percentages for soil texture classification



Prior to classifying soils, it is important to discuss the three mineral components of soils that are categorized based on particle size: sands, silts, and clays. Particles that range from about 0.05 mm to 2 mm in size are sands. Particles between 0.002 mm and 0.05 mm are classified as silts. Particles less than 0.002 mm are clays. Further breakdown based on soil textures is as follows:

Sands: Contain more than 85% sand, and the percentage of silt plus 1.5 times the percentage of clay is less than 15.

1. *Coarse sand*: Greater than or equal to 25% or more very coarse and coarse sand; less than 50% ay other single grade of sand.
2. *Sand*: Greater than or equal to 25% or more very coarse, coarse, and medium sand; less than 25% very coarse and coarse sand; less than 50% fine sand and/or very fine sand.
3. *Fine sand*: 50% or more fine sand; less than 25% very coarse, coarse, and medium sand; less than 50% very fine sand
4. *Very fine sand*: 50% or more very fine sand

Loamy sands: Between 70 and 91% sand and the percentage of silt plus 1.5 times the percentage of clay is 15 or greater; the percentage of silt plus twice the percentage of clay is less than 30.

1. *Loamy coarse sand:* Greater than or equal to 25% or more very coarse and coarse sand; less tha 50% any other single grade of sand
2. *Loamy sand:* Greater than or equal to 25% or more very coarse, coarse, and medium sand; less than 25% very coarse and coarse sand; less than 50% fine and/or very fine sand
3. *Loamy fine sand*: Greater than or equal to 50% fine sand; less than 50% very fine sand; less than 25% very coarse, coarse, and medium sand
4. *Loamy very fine sand*: 50% or more very fine sand.

Sandy loams: Between 7% and 20% clay, greater than 52% sand, and the percentage of silt plus twice the percentage of clay is 30 or more; or, less than 7% clay, less than 50% silt, and more than 43% sand.

1. *Coarse sandy loam*: Greater than or equal to 25% or more very coarse and coarse sand; less than 50% any other single grade of sand
2. *Sandy loam:* Greater than or equal to 30% very coarse, coarse, and medium sand; less than 25% very coarse and coarse sand; less than 30% fine and/or very fine sand. Or, less than or equal to 15% very coarse, coarse, and medium sand, less than 30% fine and/or very fine sand, and less than or equal to 40% fine or very fine sand.
3. *Fine sandy loam*: Greater than or equal to 30% fine sand, and less than 30% very fine sand. Or, between 15%-30% very coarse, coarse, and medium sand. Or, greater than or equal to 40% fine and very fine sand, one half of which is fine sand, and less than or equal to 15% very coarse, coarse, and medium sand.
4. *Very fine sandy loam*: Greater than or equal to 30% or more very fine sand and less than 15% very coarse, coarse, and medium sand. Or, greater than 40% fine and very fine sand, more than half of which is very fine sand, and less than 15% very coarse, coarse, and medium sand.

Loam: Between 7% and 27% clay, 28% and 50% silt, and 52% or less sand.

1. *Silt loam*: Greater than or equal to 50% or more silt and between 12% and 27% clay. Or, between 50% and 80% silt and less than 12% clay
2. *Silt*: greater than or equal to 80% or more silt, and less than 12% clay.
3. *Sandy clay loam*: Between 20% and 35% clay, less than 28% silt, and more than 45% sand.
4. *Clay loam*: Between 27% and 40% clay and more than 20%-46% sand.
5. *Silty clay loam*: Between 27% and 40% clay and less than or equal to 20% sand.
6. *Sandy clay*: Greater than or equal to 35% clay and greater of equal to than 45% sand
7. *Silty clay*: Greater than or equal to 40% clay and greater than or equal to 40% silt.

4*Clay*: Greater than or equal to 40% or more clay, less than 45% sand, and less than 40% silt.

Appendix F: Climate Table

State	City	Spring Frost Date	Fall Frost Date	Elevation (ft)	Low Temperature (F)	High Temperature (F)	Precipitation (in)
AK	Barrow	8/4	7/24	26	-54	76	4.5
AK	Bethel	6/21	9/5	39	-48	84	15
AK	Fairbanks	5/25	8/25	499	-62	96	10.9
AK	Gulkana	6/23	8/9	1578	-58	90	10.8
AK	Juneau	5/30	9/5	23	-22	90	53.6
AK	King Salmon	6/8	8/27	49	-48	85	19.8
AK	Nome	7/8	8/17	10	-54	86	14.9
AK	Sitka Airport	5/7	10/11	66	0	88	85.9
AL	Birmingham	4/14	10/24	630	-6	106	54.6
AL	Mobile	3/19	11/5	30	3	103	64
AL	Montgomery	3/28	10/29	200	0	104	53.4
AL	Tuscaloosa	4/8	10/20	187	-1	105	55
AR	Fayetteville (Airport)	5/3	10/4	1250	-15	106	43.8
AR	Fort Smith	4/14	10/18	446	-10	110	40.9
AR	Little Rock	4/8	10/27	259	-4	112	50.8
AR	Pine Bluff	4/4	10/26	207	-2	107	47.7
AR	Texarkana	3/29	10/29	361	5	107	44.2
AZ	Flagstaff	6/26	9/9	7004	-23	97	22.9
AZ	Phoenix	3/16	11/18	1112	19	122	7.7
AZ	Tuscon	3/27	11/7	2558	16	117	12
AZ	Yuma	2/19	12/14	207	24	122	3.2
CA	Bakersfield	3/3	11/20	492	19	114	5.7
CA	Barstow	4/15	10/29	1929	7	117	3.7
CA	Berkeley	1/19	12/26	6	26	104	18.2
CA	Bishop	5/25	9/26	4146	-8	109	5.4
CA	Blythe	3/1	11/28	262	20	122	3.3
CA	Eureka	3/14	11/15	59	21	86	37.5
CA	Fresno	4/1	11/7	338	18	111	10.6
CA	Los Angeles	2/11	12/8	148	30	110	12.1
CA	Sacramento	3/23	11/14	69	18	115	17.5
CA	San Diego	3/30	11/12	42	32	108	9.1
CA	San Francisco	1/24	12/8	7	24	106	19.7
CA	Santa Barbara	2/26	12/4	16	20	109	16.2
CO	Denver	5/20	9/20	5333	-25	103	15.4
CO	Grand Junction	6/1	9/16	4848	-23	105	8.7
CT	Hartford	5/12	9/23	174	-26	102	44.1
DE	Dover	4/19	10/15	36	0	101	36
DE	Wilmington	4/25	10/15	36	-14	102	40.8
FL	Gainesville	3/29	11/5	157	10	102	51.4
FL	Jacksonville	3/14	11/16	30	7	103	51.3
FL	Miami	none	none	13	30	98	55.9
FL	Orlando (Sanford)	3/4	12/3	98	19	100	47.7

State	City	Spring Frost Date	Fall Frost Date	Elevation (ft)	Low Temperature (F)	High Temperature (F)	Precipitation (in)
FL	Pensacola	3/20	11/8	76	6	105	58.9
FL	Tallahassee	4/5	10/28	69	6	103	65.8
FL	Tampa	2/25	12/3	7	18	99	43.9
GA	Albany	3/31	10/26	208	7	101	48.3
GA	Atlanta	4/10	10/25	977	-8	105	50.8
GA	Augusta	4/15	10/23	134	-1	108	44.6
GA	Brunswick	3/18	11/15	10	13	99	53
GA	Columbus	4/8	10/27	387	-2	104	51
GA	Macon	4/4	10/25	354	-6	108	44.6
GA	Savannah	3/30	10/31	46	3	105	49.2
HI	Hilo	none	none	30	53	94	129.7
HI	Honolulu	none	none	39	52	94	22.1
HI	Lihue	none	none	103	50	90	43.1
IA	Cedar Rapids	5/13	9/25	902	-28	104	33.4
IA	Des Moines	5/9	9/21	968	-24	108	33.1
IA	Mason City	5/20	9/16	1174	-30	104	32.7
IA	Ottumwa	5/2	10/5	840	-23	105	33.8
ID	Boise	5/26	9/22	2706	-25	110	12.1
ID	Idaho Falls	6/14	9/4	4728	-38	102	10.9
ID	Pocatello	6/12	9/6	4477	-33	104	12.1
IL	Chicago	4/25	10/22	658	-27	104	35.8
IL	Peoria	5/8	10/6	653	-25	105	36.2
IL	Rockford	5/13	9/25	725	-27	104	37.1
IL	Springfield	5/1	10/6	617	-22	106	35.3
IN	Evansville	4/23	10/12	430	-21	104	43.1
IN	Ft. Wayne	5/15	9/25	856	-22	106	34.7
IN	Indianapolis	5/9	10/7	807	-23	103	39.9
KS	Dodge City	5/7	10/11	2593	-21	109	21.5
KS	Goodland	5/16	9/23	3680	-27	108	18.2
KS	Salina	5/4	10/9	1275	-24	109	30.1
KS	Topeka	5/4	10/1	879	-26	110	35.2
KS	Wichita	5/1	10/10	1321	-21	112	29.3
KY	Bowling Green	4/28	10/7	538	-21	107	51
KY	Lexington	5/3	10/10	1063	-21	103	44.5
KY	Padicah	4/18	10/15	397	-15	105	48.9
LA	Alexandria	3/26	10/31	77	5	104	53.1
LA	Baton Rouge	3/18	11/4	59	-8	102	60.8
LA	Lafayette	3/17	11/6	36	9	102	58.6
LA	Lake Charles	3/18	11/5	9	11	103	55.3
LA	New Orleans	3/21	11/15	7	11	102	62.2
LA	Shreveport	4/2	10/27	174	3	107	46.1
MA	Boston	5/3	10/5	30	-7	102	41.5
MD	Baltimore	4/11	10/29	148	-7	105	40.7
ME	Augusta	5/12	9/22	354	-19	97	42
MI	Detroit	5/12	10/9	619	-13	103	26.6

State	City	Spring Frost Date	Fall Frost Date	Elevation (ft)	Low Temperature (F)	High Temperature (F)	Precipitation (in)
MI	Lansing	5/31	9/18	859	-29	100	30.6
MI	Marquette	5/25	10/4	1414	-34	99	36
MI	Muskegon	5/24	9/24	644	-15	99	32.6
MI	Traverse City	6/9	9/17	625	-37	101	29.8
MN	Duluth	6/4	9/10	1424	-39	97	30
MN	International Falls	6/9	9/4	1118	-46	98	24.3
MN	Minneapolis	5/21	9/15	833	-34	105	28.4
MO	Joplin	4/26	10/13	987	-15	108	43.2
MO	Kansas City	4/30	10/9	742	-19	110	36.1
MO	Springfield	5/2	10/8	1364	-17	108	43.2
MO	St. Louis	4/30	10/8	564	-18	107	37.5
MS	Columbus	4/11	10/15	200	-2	104	55
MS	Jackson	4/7	10/14	291	2	106	55.4
MS	Meridian	4/12	10/19	295	0	107	56.7
MT	Billings	5/29	9/6	3569	-32	105	15.1
MT	Bozeman	6/19	8/31	4467	-46	103	14.7
MT	Butte	7/1	8/23	5530	-52	99	12.2
MT	Helena	6/2	9/2	3827	-38	105	11.6
NC	Asheville	4/24	10/11	2239	-7	95	38.8
NC	Charlotte	4/25	10/14	787	-5	103	43.1
NC	Greensboro	4/22	10/14	902	-8	103	42.6
NC	Raleigh	4/29	10/16	443	-9	105	41.4
ND	Bismark	5/26	9/7	1673	-43	109	15.5
ND	Dickinson	6/9	8/28	2542	-35	109	16.1
ND	Fargo	5/25	9/12	895	-35	106	19.5
ND	Minot	5/31	9/2	1722	-36	106	18.7
NE	Grand Island	5/16	9/26	1853	-28	110	24.9
NE	Lincoln	5/9	9/30	1181	-33	108	28.8
NE	North Platte	5/25	9/10	2788	-34	108	19.3
NE	Omaha	5/12	9/23	1027	-23	110	29.9
NE	Scottsbluff	5/25	9/14	3854	-42	109	15.3
NH	Concord	6/9	9/8	338	-33	102	36.4
NH	Mt. Washington	7/29	8/2	6268	-46	72	98.9
NJ	Atlantic City	5/15	9/28	52	-2	102	36.7
NJ	Millville	4/29	10/10	72	-10	102	42.1
NJ	Newark	4/15	10/26	7	-8	105	43.9
NJ	Trenton	4/15	10/23	190	-4	102	42
NM	Albuquerque	5/25	9/26	5104	-17	105	8.9
NM	Gallup	6/14	9/15	6465	-34	99	11.3
NM	Las Vegas	5/29	9/22	6501	-26	99	16.1
NV	Ely	6/30	8/21	6262	-30	100	10.1
NV	Las Vagas	4/3	11/7	2030	12	117	3.4
NV	Reno	6/19	8/23	4526	-16	105	7.5
NV	Winnemucca	6/26	8/26	4300	-37	108	8.2

State	City	Spring Frost Date	Fall Frost Date	Elevation (ft)	Low Temperature (F)	High Temperature (F)	Precipitation (in)
NY	Albany	5/24	9/19	292	-28	99	36.1
NY	Buffalo	5/20	9/23	705	-20	97	38.6
NY	New York City	4/13	10/27	98	-2	104	47.2
NY	Rochester	5/18	9/29	544	-19	98	31.9
NY	Syracuse	5/14	10/3	426	-26	97	38.9
OH	Akron	5/21	10/2	1214	-24	101	36.6
OH	Cincinnati	4/29	10/13	760	-15	101	39.7
OH	Cleveland	5/18	10/5	804	-19	104	36.6
OH	Columbus	5/9	10/3	833	-19	101	38.1
OH	Dayton	4/27	10/16	1004	-24	102	36.6
OH	Toledo	5/16	9/29	669	-20	104	32.9
OH	Youngstown	5/24	9/29	1178	-20	100	37.4
OK	Okalahoma City	4/15	10/16	1280	-8	110	33.3
OK	Tulsa	4/13	10/21	676	-8	110	40.6
OR	Baker City Airport	6/29	8/26	3372	-39	106	10.6
OR	Eugene	5/22	10/1	430	-7	108	49.4
OR	Klamath	6/28	8/31	4099	-25	100	12.6
OR	Pendleton	5/3	10/5	1200	-19	113	12
OR	Portland	4/26	10/18	33	6	107	36.3
OR	Redmond	7/17	8/20	3050	-28	108	8.6
OR	Salem	5/22	9/28	180	-5	108	39.2
PA	Allentown	5/5	10/2	380	-12	105	43.5
PA	Harrisburg	5/4	10/4	340	-9	107	40.5
PA	Philadelphia	4/14	10/28	27	-7	104	41.5
PA	Pittsburg	5/26	9/20	1223	-18	103	36.8
PA	Williamsport	5/16	9/30	522	-17	103	40.7
SC	Beaufort	3/28	11/1	21	10	104	51.2
SC	Charleston	4/6	10/30	49	6	104	51.5
SC	Columbia	4/17	10/16	226	-1	107	49.9
SC	Greenville	5/5	10/8	956	-6	103	50.6
SD	Huron	5/27	9/15	1282	-39	112	20.1
SD	Pierre	6/2	9/8	1469	-33	114	18.7
SD	Rapid City	5/26	9/14	3247	-23	109	18.6
SD	Sioux Falls	5/24	9/17	1440	-36	110	23.8
TN	Chattanooga	4/18	10/19	689	-10	105	53.5
TN	Knoxville	4/9	10/23	981	-24	102	47.1
TN	Memphis	4/8	10/27	510	-14	106	50.9
TN	Nashville	4/16	10/14	600	-17	105	47.3
TX	Amarillo	4/30	10/14	3615	-12	108	19.5
TX	Austin	3/21	11/5	617	4	106	31.9
TX	Brownsville	2/15	12/17	20	16	106	26.6
TX	Dalhart	5/9	10/11	3995	-18	107	17.5
TX	Dallas/ Ft Worth	4/8	10/24	574	-1	113	33.7
TX	El Paso	4/14	10/28	3913	-8	112	8.8

State	City	Spring Frost Date	Fall Frost Date	Elevation (ft)	Low Temperature (F)	High Temperature (F)	Precipitation (in)
TX	Houston	3/17	11/14	102	7	107	47
TX	Midland	4/11	10/21	2857	-11	112	15
TX	San Antonio	3/23	11/6	581	6	108	31
TX	Wichita Falls	4/13	10/24	1027	-8	117	28.9
UT	Cedar City	6/8	9/14	5852	-24	105	11.5
UT	Logan	5/22	9/27	4300	-13	104	18.9
UT	Salt Lake City	5/18	9/29	4225	-18	104	16.2
UT	Wendover	5/8	10/10	4241	-10	102	5.4
VA	Norfolk	4/6	10/31	26	-3	104	44.6
VA	Richmond	4/27	10/13	164	-8	105	43.1
VA	Roanoake	4/29	10/5	1174	-11	105	41.1
VT	Burlington	5/25	9/19	335	-30	99	34.4
VT	Montpelier	6/3	9/8	1099	-34	97	34.6
WA	Bellingham	5/6	10/1	59	-1	94	13.7
WA	Olympia	5/17	9/30	36	-8	104	50.5
WA	Seattle	4/20	10/27	125	9	96	37.1
WA	Spokane	5/20	9/19	1922	-25	108	16.5
WA	Walla Walla	4/19	10/20	1166	-24	114	19.5
WA	Yakima	5/20	9/21	1135	-17	110	8
WI	Eau Claire	5/26	9/15	892	-39	104	31.6
WI	Green Bay	5/26	9/18	699	-29	99	28.8
WI	Lacrosse	5/15	9/29	672	-36	105	30.6
WI	Madison	5/13	9/25	872	-30	104	30.9
WI	Milwaukee	5/20	9/26	672	-26	103	32.9
WI	Wausau	5/22	9/6	1191	-36	99	33
WV	Charleston	5/9	10/5	951	-15	104	42.5
WV	Parkersburg	5/9	10/2	840	-20	102	41.4
WY	Casper	6/8	9/7	5320	-41	102	12.5
WY	Cheyenne	6/8	9/9	6143	-29	98	14.4
WY	Laramie	6/26	8/26	7186	-50	94	10.6
WY	Rock Springs	6/11	9/1	6370	-37	96	9.5
WY	Sheridan	6/6	9/7	3952	-37	106	14.5

Appendix G

Resources

Internet Resources:

1. RTDF Phytoremediation Profiles website
   http://rtdf.org/public/phyto/siteprof/index.cfm

2. EPA REACH IT website
   http://www.epareachit.org/

3. CLU-IN Innovative Remediation Technologies: Field Scale Demonstration Project Database and Report
   http://clu-in.org/products/nairt/

4. EPA Superfund Innovative Technology Evaluation (SITE) Project Status Information
   http://www.epa.gov/ORD/SITE/projectstatus.htm

5. Federal Remediation Technologies Roundtable (FRTR)
   http://www.frtr.gov/

6. NIST Chemistry Webbook
   http://webbook.nist.gov/chemistry/

Database resources:

- Science Direct
- LexisNexis
- EBSCOhost
- MEDLINE
- BIOSIS
- National Technical Information Service (NTIS)
- Energy Science and Technology
- General Science Abstracts
- Waternet
- Agricola
- CAB Abstracts
- Science.gov
- USDA PLANTS database

Appendix H

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